# PRACTICAL USES
OF THE
# WAVE METER IN WIRELESS TELEGRAPHY

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# PRACTICAL USES
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# WAVE METER
IN
# WIRELESS TELEGRAPHY

BY

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# PREFACE

In its original form this work was first privately printed for reference use at the Army Signal School, Fort Leavenworth, Kansas, and, in 1912, was, by direction of the Secretary of War, adopted fôr use at that school.

The text has since been carefully revised and amended, and in its present form is now published for commercial and technical school use.

The author desires to acknowledge his indebtedness to Prof. G. W. Pierce for his careful criticism of the manuscript and for the many suggestions that have added materially to the correctness of the present edition. The author's thanks are also due to Mr. E. R. Cram, Radio Engineer, U. S. Signal Corps, for many valuable suggestions regarding the revision, and to Major Edgar Russel, Signal Corps, U. S. A., for his kind assistance and encouragement.

The literature of the Telefunken Wireless Telegraph Company has been freely consulted in preparing the data on the meters of that Company.

J. O. M.

GALVESTON, TEXAS,
*October* 1, 1913.

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# PRACTICAL USES OF THE WAVE METER IN WIRELESS TELEGRAPHY

## CHAPTER I

### GENERAL REMARKS

A wave meter is essentially a calibrated, closed oscillatory circuit, having inductance and capacity, either or both of which are variable. The resistance of such a circuit is small in comparison with its inductance. It is, in reality, a small wireless set, which, when used with any one of many forms of detector usually supplied with it, can be used as a receiving set, from which we can read directly the wave length emitted by any wireless sending circuit, or coupled oscillatory circuits; or, when used with proper means for exciting it, may be used as a miniature sending set, with which we can excite, in any nearby oscillatory circuit, waves of any desired length within the limits of the wave meter.

As the operation of this device, and the intelligent use of it are based upon a knowledge of the well-known principles of resonance, a brief review of these, and of some of the preliminary principles of wireless telegraphy may serve to make the matter clearer to some who take it up for the first time, or who have left the theory far behind in the practical operation of wireless stations.

### DEFINITIONS

**Alternating Current.**—An alternating current is one that periodically passes through all values, flowing first in one direction, then in the other. This alternating current is due to an alternating e.m.f. that gradually increases from zero to a positive maximum, then decreases to zero, and then reverses its sign, increases to a negative maximum and then decreases to zero.

**Amplitude.**—The greatest positive value, or greatest negative value of the alternating current or of potential, is called the amplitude.

Each complete set of values is called a cycle. Half a cycle is called an alternation.

The time it takes the current or the potential to complete one cycle or two alternations, is called a period ($T$).

The number of complete periods or cycles executed in a second is called the frequency ($n$).

A high-frequency current is one in which the frequency is reckoned in thousands.

When the frequency rises to any value between a hundred thousand and a million, electric oscillations are said to exist in the circuit.

When an alternating current of very high frequency and of constant amplitude exists in a circuit, undamped oscillations are produced.

**Damped Oscillations.**—Damped oscillations are those consisting of a limited number of alternations, the amplitude of which is continually decreasing.

When damped oscillations exist in a circuit without spark gap they decay in amplitude according to the law that the ratio of the amplitude of current of any oscillation to that of the next succeeding it is constant, and this constant ratio is called the *damping factor* of the oscillations. The Napierian logarithm of the ratio of the amplitude of one oscillation to that of the succeeding one is called the *logarithmic decrement*, or briefly, the decrement.

A *train* of oscillations is said to be *highly damped* if the logarithmic decrement is large; *feebly damped* if it is small.

**Oscillatory Circuit.**—An oscillatory circuit is one in which some form of inductance, and some form of condenser are joined in series, the resistance of the circuit being small in comparison with the inductance.

Let $R$ = Resistance in ohms of the circuit.

$C$ = Capacity in farads.

$L$ = Inductance in henrys.

Then, if $R$ is greater than $2\sqrt{\frac{L}{C}}$ in a circuit through which a condenser is discharged, no oscillation will take place in the circuit, and the circuit is called aperiodic.

If, however, $R$ is less than $2\sqrt{\frac{L}{C}}$ the discharge will be oscillatory, electricity moving backward and forward in the discharge

circuit with gradually decreasing amplitude, until the energy of the condenser charge is completely dissipated by resistance and radiation.

For any oscillatory circuit, then, it may be shown that the circuit vibrates in its natural period equal to

$$T=2\pi\sqrt{LC}$$

and the frequency of the electric oscillations equals

$$n=\frac{1}{T} \text{ and } n=\frac{1}{2\pi\sqrt{LC}}$$

where $T$ is measured in seconds, $L$ in henrys, and $C$ in farads.

The above formulæ are only approximate, but considered sufficiently accurate for practical purposes.

The formula for the frequency may be reduced, for convenience in calculation, to the following form:

$$n=\frac{5.033\times10^{6}}{\sqrt{C \text{ mfds.} \times L \text{ cm.}}}$$

where the inductance, $L$, is in absolute electromagnetic units, that is, in centimeters, and $C$, the capacity, in microfarads.

1 microhenry $=0.000001$ henry $=1000$ cm.

1 microfarad $=0.000001$ farad

**Oscillation Constant.**—The expression $\sqrt{C\times L}$ is sometimes called the oscillation constant of the circuit. In the United States it is more common to define the "oscillation constant" as simply the product of the capacity times the inductance, and further, in the tables furnished to the Signal Corps stations equipped with the receiving sets of the Wireless Specialty Apparatus Co., the "oscillation constant" is given as the product of the capacity in microfarads and the inductance in microhenrys.

**Syntonic Circuits.**—When two oscillatory circuits have the same time-period, or period, as it is called, they are called syntonic circuits, and are said to be in resonance with each other. This is the case when the oscillation constants, or, without extracting the square root, when the product of the capacity and inductance of the two circuits is the same, though the individual values may be very different. Thus, a circuit having an inductance of 5000 cm. and a capacity of 0.005 microfarads will have the same period, and, as we shall see later, the same wave length, as a circuit having an inductance of 25,000 cm. and 0.001 mfds.

If oscillations are set up in a circuit having a certain period, and, if the period of another oscillatory circuit near it is gradually changed, either by changing its inductance or its capacity, until the period of the latter circuit is made the same as that of the first, a current-indicating device in the second circuit will give evidence of a considerable increase of current in this circuit as it approaches the resonance condition, and of a decrease of the current, the further the period of the second circuit recedes from that of the exciting circuit.

If this second oscillatory circuit, containing the current-indicating device, is provided with a scale for directly reading therefrom the period of the circuit for any given value of its variable inductance or variable capacity, we may say that the period of the exciting circuit is the same as that read from the scale or taken from the calibration curve of the second circuit.

**Operation of the Wave Meter.**—This is the principle of operation of the wave meter, and the operation of bringing one oscillatory circuit into resonance with another is called tuning.

The relation between the wave length, $\lambda$, the velocity of propagation of the wave ($V$), and the period ($T$) of an oscillatory system is given by the equation

$$V=\frac{\lambda}{T} \text{ or, } T=\frac{\lambda}{V}$$

$$\text{and, since } n=\frac{1}{T}$$

$$\text{then, } V=n\lambda \text{ or, } \lambda=\frac{V}{n}$$

that is, the wave length in meters is equal to the velocity of the wave in meters per second divided by the frequency in cycles per second,

where $V$ is taken as 300,000,000 meters per second,

$\lambda$ the wave length in meters,

and $n$ the frequency.

The expression for the wave length in meters,

$$\lambda=\frac{V}{n}$$

may be reduced to the very convenient practical form,

$$\lambda \text{ meters} = 59.6\sqrt{C \text{ mfds.} \times L \text{ cm.}}$$

in which form it may be used for the purpose of calculating the values of capacities or inductances, as will be described later.

Wave meters are usually calibrated to read directly in meters; and, the wave length of a circuit being known, its period or its frequency can easily be calculated from the formulæ given above.

**Wave Meter Circuits.**—These are all reducible to the elementary form shown in Fig. 1, which represents a closed oscillatory circuit having a fixed inductance, $L$, and a variable condenser, $C$, though most wave meters are supplied with several fixed inductances, which are easily substituted for one another in the wave meter circuit. These enable the wave meter to have a range, usually from about 150 to 6000 meters, in the various types seen at present.

**The Wave Meter as a Receiving Device.**—For the purpose of

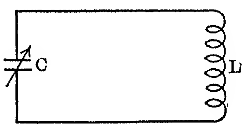


FIG. 1.

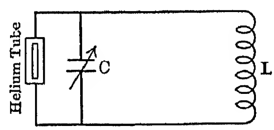


FIG. 2.

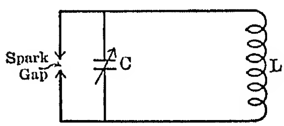


FIG. 3.

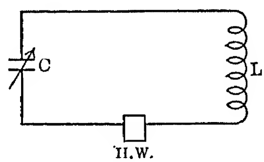


FIG. 4.

FIGS. 1 to 4.—Wave meter attachments.

measuring the wave lengths of sending sets, the wave meter is usually provided with one or more of the following forms of energy-indicating devices shown in Figs. 2, 3, 4, 5, 6, 7, 8, 9, and 10:

1. A small tube (Fig. 2) containing helium or neon gas is connected across the terminals of the variable condenser, $C$, and glows when the resonance condition is reached.

2. A very minute spark gap (Fig. 3) placed across the variable condenser will spark when resonance is obtained. This is sometimes added to wave meters using a helium tube to prevent burning out the tube, and sparking in the variable condenser itself.

3. A hot-wire ammeter (Fig. 4), calibrated to register from 0 to 100 milliamperes, or a thermo-ammeter, such as a Duddell, of very low resistance, with about the same scale limits, can be inserted directly into the wave meter circuit, and is the most accurate and useful indicating device, since it not only indicates the exact point of resonance, but enables us to plot resonance curves showing the amount of current in the wave meter circuit, not only at the resonance position, but also as the wave meter departs from, or approaches, exact syntony. In practice, most well designed wave meters have such hot wire instruments either

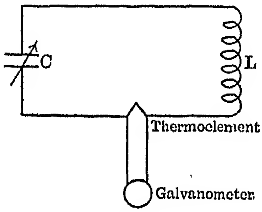


Fig. 5.

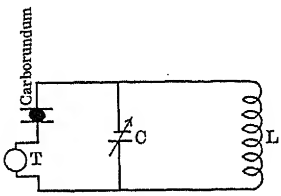


Fig. 6.

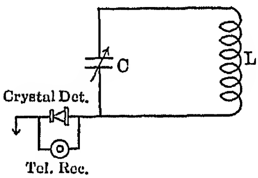


Fig. 7.

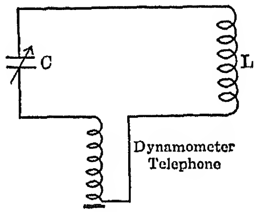


Fig. 8.

Figs. 5 to 8.—Wave meter attachments for measuring the sending apparatus.

inductively connected or provided with a low resistance shunt. (Fig. 25.) The instrument is usually a hot-wire wattmeter.

4. A thermo-element (Fig. 5) of low resistance, constructed as described later (see Fig. 26 and accompanying text), is inserted in the wave meter circuit, and shunts a low resistance galvanometer. The readings of the galvanometer are proportional to the square of the oscillatory current through the junction, and, as the galvanometer and the thermo-element can be calibrated for alternating currents by comparison with a hot-wire ammeter, this form of indicating device may be used not only to indicate resonance, but, by its use, resonance curves may be plotted as with the hot-wire ammeter, and the damping of any circuit

determined as shown later. In using this device it may be found advisable to introduce some inductance in the galvanometer leads.

5. If the variable condenser of the wave meter (Fig. 6) is shunted by a circuit containing a detector of the crystal type, such as carborundum, the sensibility of which is not affected by nearby sending apparatus, in series with a high resistance telephone receiver, *T*, the maximum loudness of the sound heard in the telephone receiver will indicate when the wave meter is in resonance with the sending circuit to which it is being tuned. This is the detecting device supplied with the Marconi wave meter, and with one type of Telefunken instrument.

Professor George W. Pierce is of the opinion that, due to the possibility of the detector affecting the period of the meter, it is better, or at least simpler, to connect the detector unilaterally, as shown in Fig. 7, and shunt the receivers about it. This indicating device can always be improvised at any station, and applied to any wave meter. It is especially recommended for measurement of the natural wave length of the antenna. Any detector will do, but iron pyrites or carborundum is recommended.

6. A dynamometer telephone (Fig. 8), consisting of a small coil of wire wound on a small, hard rubber bobbin, and placed near a diaphragm of copper or silver, will, due to the reaction between the coil and the disc, when an oscillatory current is sent through the coil, indicate the resonance point by the maximum loudness of the sound heard in the telephone. The coil of wire in the dynamometer telephone, being an inductance, must be in the wave meter circuit, when the latter is being calibrated, or if removed for the purpose of introducing some other device, as seen later (Fig. 13 and accompanying explanation), a coil of wire having exactly similar inductance must be inserted in the circuit, in order that the readings of the wave meter may be correct.

This is the form of receiving device furnished with the Pierce wave meter.

7. An aperiodic circuit, *A* (Fig. 9), consisting of an inductance, a detector of the carborundum, iron pyrite, or silicon steel-wire type, and a small stopping condenser of about 0.003 mfd. capacity shunted by a pair of wireless telephone receivers, if loosely coupled with the wave meter inductance, will indicate, by the loudness of the sound in the telephone receivers, when the wave meter

is in resonance with the sending circuit. Needless to say, the detector must be in a sensitive adjustment to permit of the loosest coupling between the coils of the aperiodic circuit and the receptor loop of the wave meter.

8. The telephone receiver of the aperiodic circuit may be replaced by a galvanometer as shown in Fig. 10. Quantitative measurements of currents in the circuit, which afford a better approximation of the exact point of resonance, may then be made by this means, and resonance curves plotted, if desired, if care be taken to preserve the coupling of the wave meter, aperiodic circuit, and circuit to be measured, unchanged throughout the series of measurements resulting in a curve.

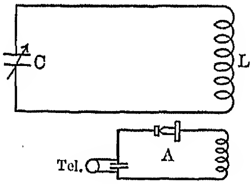


Fig. 9.

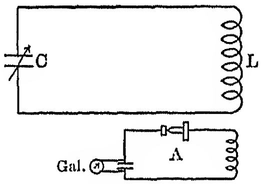


Fig. 10.

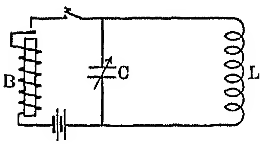


Fig. 11.

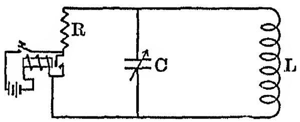


Fig. 12.

Figs. 9 to 12.—Wave meter attachments, receiving and sending.

The deflections of the galvanometer are to each other as the square of the current passing through it, and, if the galvanometer shunting the detector has been previously calibrated, by comparison with a known standard, the currents passing through the galvanometer may be read directly from the calibration curve previously prepared.

**The Wave Meter as a Sending Set.**—For the purpose of measuring the wave length of any given adjustment of the receiving apparatus of a station, or, in any other measurement, where it is necessary to send out waves of definite length by means of a wave meter, it is necessary to charge the variable air condenser of the wave meter continuously from some source and have it discharge through the inductance of the wave meter.

The simplest and most efficient way of doing this is indicated in Fig. 11, where the condenser is excited by the "whipcrack" method.

A circuit consisting of a buzzer, *B*, in series with a couple of cells of dry-battery, and a key or switch, is tied to the terminals of the variable condenser of the wave meter. When the key is depressed, or the switch closed, the current through the inductance, *L*, of the wave meter has energy $\frac{1}{2}LI^2$, and when the buzzer circuit breaks, this energy oscillates between the condenser and the inductance of the wave meter, and sets up oscillations in any oscillatory circuit to which the wave meter may be coupled.

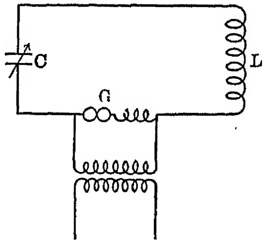


FIG. 13.—Wave meter using induction coil and spark gap for excitation.

The wave length emitted by the wave meter is that indicated by the condenser pointer passing over the scale of wave lengths.

A small medical shocking coil is a convenient form of buzzer to be inserted for the purpose mentioned, the primary alone being used. It is to be noted that the buzzer circuit is completed through the inductance of the wave meter.

Another form of buzzer-excited circuit is that shown in Fig. 12. The buzzer used in this circuit is an ordinary Signal Corps Field Buzzer, Model 1905. Across the make-and-break of the buzzer, the condenser of the wave meter is shunted. It is, however, necessary to have a non-inductive resistance, R, in series as shown in the diagram. This buzzer gives a high, even note, which is very satisfactory for use with the wave meter as a sending device.

A third form of attachment to make the wave meter a sending set is that shown in Fig. 13. This is the form of sending device furnished with the Pierce wave meter. A miniature spark gap, *G*, is inserted in the wave meter circuit, and a small induction coil giving anywhere from a quarter to a one-inch spark, operated on a couple of cells of battery, is used to charge the wave meter condenser; the secondary of the spark coil being attached to the spark gap as shown. As the plates of the condenser, *C*, are usually very close together, sparking will take place in the condenser, unless the spark gap is reduced to the smallest possible

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width. From 0.2 to 0.1 mm. is the ordinary width of gap used. As the Pierce wave meter uses the dynamometer telephone as a receiving device, the inductance of the dynamometer telephone which is removed when the spark gap is inserted, is replaced by a coil in the base of the spark gap, which has the same inductance as the telephone.

## CHAPTER II

### TYPES OF WAVE METERS IN USE IN THE U. S. SIGNAL CORPS

**The Pierce Wave Meter.**—A diagram of the connections of this meter is shown in Fig. 14.

Ordinarily no indicating device other than the dynamometer telephone is supplied with this wave meter, though a helium tube may be used with it.

This telephone is to be attached to the binding posts, which are near together to the left of the wave meter scale. If it be desired to attach a helium tube, the telephone should be left in circuit, and the helium tube is shunted around the condenser by two leads which are attached, one to the left hand binding post of the two used for the telephone receivers, and the other to the idle binding post at the back of the instrument.

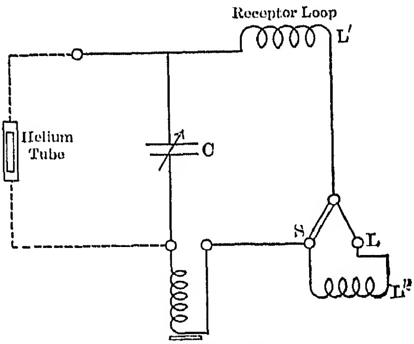


FIG. 14.—Pierce wave meter connections.

The smaller inductance, $L'$ (receptor loop), is wound on a hard rubber ring which is pivoted at the back of the instrument, so as to permit it to be revolved into any desired position. Another inductance, $L''$, of many turns, is placed in the base of the wave meter, and is used for the purpose of increasing the wave length of the circuit, when measuring long waves.

A three-point switch at the right of the instrument, marked $L$ and $S$, cuts in either all or only part of the inductance as desired. For waves up to 700 m. put the switch on $S$ (short waves), and read the wave length in meters from the position of the pointer over the red scale. This scale reads as low as 150 m.

The position of the pointer for maximum sound in the telephone is the wave length in meters. If the switch is on *L* (long waves), the black scale should be read and the wave lengths in meters obtained from it. The range of the black scale is between 500 and 2320 meters.

In case the sounds in the telephone receiver are too loud for accurate determinations, their intensity may be reduced, either by moving the wave meter farther from the exciting circuit or, more conveniently, by turning the receptor loop, so that the inductive action is diminished. In the final setting it is desirable to have the sound in the telephone just audible at resonance.

**Caution.**—The makers caution users of this instrument not to attempt to open the telephone receiver, and not to change or break the leads of the telephone, as injury to the telephone will disturb the calibration.

In stowing away the apparatus the pointer should be left free from obstructions. To this end, whenever the instrument is to be transported, it is advisable to disconnect the telephone and place it in the clamp in the cover of the box, with the leads secured under the wooden buttons. The receptor loop should be folded in with knob upward, so that the pointer can be rotated under the loop without interference. In packing for shipment, put a pad of felt on top of the handle, inside the box so that the condenser cannot rotate.

**Telefunken Wave Meter Type E. KI. W.**—This wave meter was supplied several years ago with the first 2 kw. wagon set, but in the more recent sets has been superseded by the Type E. Ki. Wk. meter described later in this pamphlet.

For diagrams of connections, see Figs. 2 and 11.

The cover of the E. Ki. W. meter can be removed to facilitate the turning of the folding handle of the condenser.

Supplied with the instruments are the following parts:

A variable capacity with pointer moving over scale from 0° to 90°.

Buzzer giving approximately 500-cycle note, with switch which can be closed to give continuous buzz, or used as sending key, if desired to send regular telegraphic signals. This feature will be referred to again later.

Four flat inductance coils, readily interchangeable, giving the wave meter a range from about 300 to 3450 meters:

Coil I — 304 to 732 m.
Coil II — 657 to 1568 m.
Coil III—1425 to 2720 m.
Coil IV—2372 to 3446 m.

Parallel leads with plug contacts for connecting flat inductance coils to variable condenser.

Helium tube which can be placed across terminals of variable condenser by spring clips attached thereto. Two helium tubes are supplied with each instrument. Care must be taken to prevent protuding sealed end of glass tube from being broken off, and thus permitting gas to escape from tube.

Aperiodic circuit (see Fig. 15, and *A*, Fig. 9), supplied with

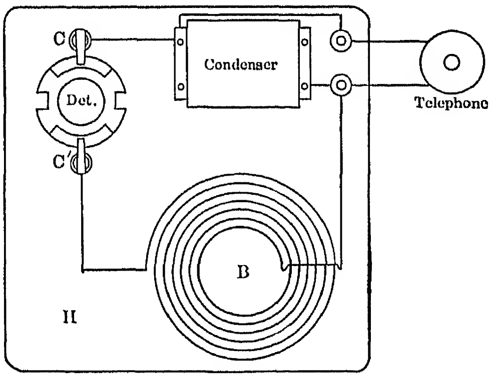



FIG. 15.—Aperiodic circuit.

this wave meter consists of a flat plate, *H*, of hard rubber, in the base of which is a flat spiral of wire, *B*, connected as shown with a small fixed mica condenser, capacity about 0.015 mfd. and spring clips, *C*, *C'*, for the insertion of one of the detectors regularly supplied with the wagon set. Binding posts are provided for the purpose of attaching the telephone receiver to fixed condenser terminals.

The four flat inductance coils of the wave meter are carried in the lower part of the wave meter case, and should be placed in their proper compartments to facilitate ready removal. The parallel leads are to be carefully coiled up and placed in the large compartment, partially occupied by the variable condenser and buzzer. The condenser pointer must always be placed at the 90° mark, before any attempt is made to place this coil of wire

in the same compartment, if injury to the condenser is to be prevented.

There is only one adjustment for the buzzer, and to regulate this the screw head immediately to the upper left of the buzzer switch must be turned with a screw-driver while the buzzer key is depressed. The buzzer is properly adjusted when it gives a clear singing note, in response to taps on the buzzer key. It will be noticed that re-adjustment of the buzzer will probably have to be made on attaching the largest of the inductance coils to the wave meter.

The scale over which the pointer moves is graduated only in degrees.

Upon each flat coil is marked in white letters the wave lengths corresponding to every ten degrees of condenser setting, thus:

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Coil II | $C=10°$ | 20° | 30° | 40° | 50° | 60° | 70° | 80° | 90° |
| | $\lambda=657$ | 818 | 965 | 1098 | 1215 | 1316 | 1409 | 1492 | 1568 |
| | 16.1 | 14.7 | 13.3 | 11.7 | 10.1 | 9.3 | 8.3 | 7.6 | |

The figures in red on the line below those in white are the increments per degree of scale reading, which are used as follows:

Suppose we find that we get resonance when using plate No. 2, and the condenser reading for resonance is 30°. This we can read directly from the scale as 965 meters. Suppose, however, that we get resonance at $42\frac{3}{4}°$, instead of 30°. We see from the table that for 40° we get 1098 meters. The red figures on the line below, between 40° and 50°, reading 11.7, indicate that for every scale division, above 40°, we must add 11.7 meters to the 40° reading, to get the correct reading of the wave length in meters; so, by multiplying $2\frac{3}{4}°$ by 11.7, we get 32 meters, which is to be added to the 40° reading. Hence, the wave length is 1130 meters.

On the other hand, if it is desired to excite in a nearby receiving set by means of the wave meter, a wave of given length, say 1000 meters, we will have to go through the following process to find what coil is to be used, and at what condenser reading the pointer must be set in order to send out the 1000 meter wave.

An inspection of the plates will show which coil has 1000 meters within its limits. Thus, we find that with coil No. 2, 30° gives 965 meters, and 40° gives 1098 meters. 1000 meters lies somewhere between 30° and 40°, so coil No. 2 is to be used.

Subtract the nearest lower-numbered white figures on the plate

from the desired wave length, in this case $1000-965=35$, and divide this quotient by the red figures between the 30° and 40° wave lengths. $35\div13.3=2.6°$, and we thus find that 2.6° are to be added to 30°, making a total of 32.6°, in order that the condenser pointer may be properly set, so that the wave meter may send out the 1000 meter wave.

For greatest accuracy, the readings of the pointer should be estimated to the nearest tenth of a degree.

The above is, perhaps, not as convenient a process as reading the wave length directly from the condenser scale, but the accuracy of this wave meter cannot be questioned, and the little extra labor used in calculation is well repaid by the accuracy of the results obtained. Considerable trouble and labor will be obviated, if, from the data given on the plates, calibration curves of wave lengths against degrees of condenser scale are plotted.

**The Type E. Ki. Wk. Meter.**—This is the type of wave meter issued at the present time with each Telefunken wagon set, for field use. A top view of this wave meter is shown in Fig. 16.

Four different inductances, any one of which can be brought in circuit with the variable air condenser by revolving the knob, *K*, are placed near the back wall of the box, *F*, where they are in inductive relation with the coupling coil, which is inserted in the groove *G*, shown at the back of the box. This coupling coil is connected to another similar coil of wire by long, parallel leads, to permit this latter coil to be brought near the circuit to be measured. The closeness of coupling between the intermediate, or coupling circuit, and the coils of the wave meter within the box may be varied by sliding the coupling coil along the groove *G*. The reaction of the coupling coil on the wave meter is practically *nil*, so that the correctness of the readings of the wave length is assured.

The indicating arm *A*, carrying an index, moves over the four different scales corresponding to the different inductances. At the little window, *W*, is seen in Roman numbers, on a colored ground, the number of the coil being used. The four arcs marked *I*, *II*, *III*, and *IV*, bearing the graduations in wave lengths corresponding to any position of arm *A*, are colored to correspond to the colors shown at *W*. Thus, the red field bearing the figures *II*, seen at *W*, indicates that we are to read the red, or second scale of wave lengths; the blue field, the fourth scale, etc.

The scales range as follows:

I. White scale—300 to 600 meters.
II. Red scale—500 to 1058 meters.
III. Yellow scale—1000 to 1950 meters.
IV. Blue scale—1600 to 3250 meters.

The wave lengths are read directly off the scale.

Attached to arm *A*, and making an angle of 90° with it, is the pointer *P*, which moves over a scale of degrees from 0° to 90°,

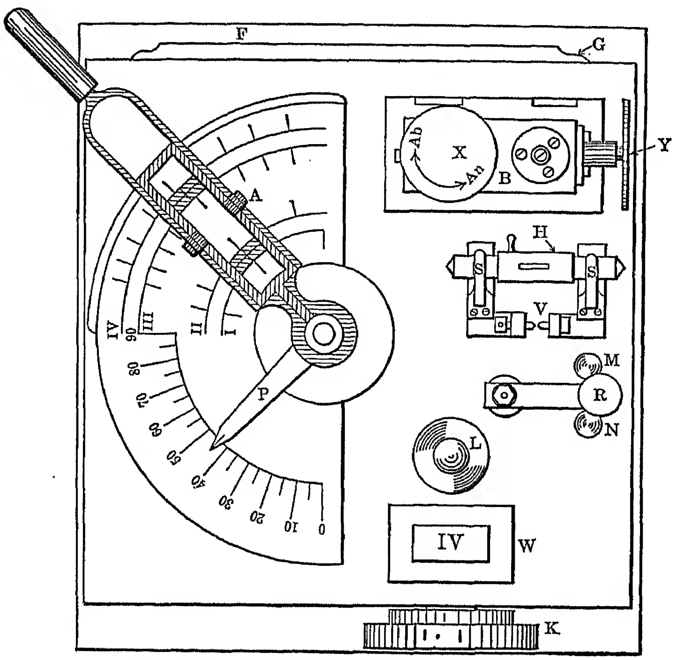



Fig. 16.—Type E. K. I. Wk. wavemeter.

which may be read if the wave lengths are taken from a curve, instead of read from wave length scales under arm *A*.

The connections are practically similar, with the exception of the multipolar combination switch wiring, to the connections of the type E. Ki. W. meter before described. The buzzer, *B*, is outside of the box and connects to the dry-battery inside by the plug connections underneath it.

Care must be exercised in adjustment of this buzzer, for the platinum cross-wires, which form the make and break contacts, may be broken by screwing too tightly together. There are two

milled adjusting heads, one of which, seen at $X$, and marked $Ab-An$, adjusts the position of one contact with reference to the other, and the other at $Y$, which adjusts the tension, causing the note of the buzzer to be raised or lowered.

When changing to the fourth coil from any of the others, it will probably be necessary to re-adjust the buzzer, since the higher resistance of this coil will decrease the direct current by which the buzzer operates. A high, singing note is best for purposes of measurement of the receiving circuit.

The usual small helium tube is attached to the condenser terminals at $S$. This is protected from heavy currents by a minute spark gap, $G$.

For very heavy currents, a small incandescent lamp, $L$, is placed in the wave meter circuit, but will rarely glow. The caution about breaking helium tubes supplied by the Telefunken Company applies to those with this meter. They should normally be carried in cotton in a small box, instead of in the spring clips $S$.

The switch, $R$, when over point $M$, can be used as a key to send Morse signals, though, when placed on point $N$, it will cause the buzzer to work continuously, as is normally done when measuring.

An aperiodic circuit, similar to that shown in Fig. 15, is furnished for use with this wave meter as a detecting device. One of the detectors belonging to the wagon set should be used with this aperiodic circuit.

**Large Telefunken Wave Meter Type E. G. W.**—This wave meter has a number of refinements not ordinarily supplied with wave meters. It has a large range of wave lengths, 100 m. to 6000 m. and has a hot-wire wattmeter, in addition to helium tubes, and detector and telephone receiver, as an indicator of current. The hot-wire wattmeter is inductively connected to the principal inductance, and thus, only a small fraction of the wave meter's energy is transferred to it. The principle of the circuits and connection of attachments are, with a few minor changes, seen, in Fig. 17, to be practically the same as in the two wave meters previously described. A double pointer on the variable condenser makes it possible to read on one scale the number of degrees corresponding to resonance, and to determine from an attached table, the wave length corresponding thereto. The other half of the pointer indicates a point

on a scale seen opposite an index on the arm. This second scale gives directly the wave length in meters for waves between 400 and 3400 meters. This latter scale is chiefly for rough determination. A curve table is used whenever the exact determination of a wave length is desired.

In the figure, *L* is the changeable inductance, *A* the connecting wire, *C* the variable condenser, *M* that part of the coil with which the hot-wire instrument is coupled, *S* the buzzer, *B* a switch by which the buzzer, or the different other instruments for showing resonance, may be inserted in circuit.

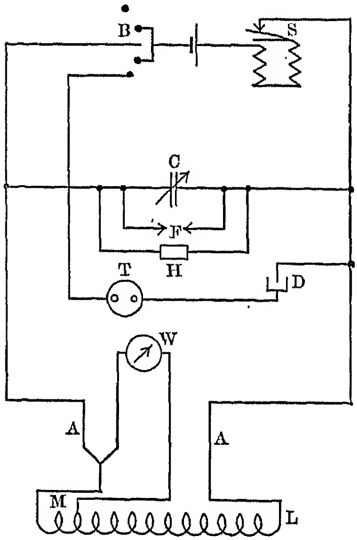


Fig. 17.—Large Telefunken wave meter, Type E. G. W.

The condenser is a plate condenser, contained in a receptacle filled with oil. Its range is from 200 to 5000 cm.

*F* is a safety spark gap around the condenser.

The inductance coils are six in number. Upon the back of each coil are shown the wave lengths falling within range of the coil. Contact between the coils and the handle is properly made only when the white marks on them are opposite one another.

The several coils, used in connection with the condenser, between 20° and 170° give approximately the following wave lengths:

| | | |
|---|---|---|
| Coil I | — | 90 to 260 m. |
| Coil II | — | 180 to 500 m. |
| Coil III | — | 400 to 1050 m. |
| Coil IV | — | 650 to 1800 m. |
| Coil V | — | 1200 to 3400 m. |
| Coil VI | — | 2100 to 5700 m. |

The hot-wire wattmeter, *W*, indicates the energy received by the wave meter. It is so loosely coupled with a few turns of the coil, *L*, that the energy drawn by the wave meter from the oscillatory circuit is extremely small, and the damping caused

by the different coils is very small and nearly constant. The knob reaching through an opening in the glass window is used to bring the pointer to the zero of the scale.

To use the hot-wire instrument, the switch, *B*, is set on the first contact.

Instead of the wattmeter, either the helium tube, or the telephone and detector may be used, if it is a question of qualitative measurement. For measuring wave lengths, one has the choice of all three devices, but for measurements of damping, the hot-wire wattmeter must be used, and it is to be noted that in all cases where the wave meter with its hot-wire wattmeter is used to obtain the logarithmic decrement, the readings of this instrument should *not* be squared as the readings are themselves the squares of the currents.

The helium tube, *H*, is connected directly to the terminals of the condenser, *C*, and in parallel with it. To use it, the tube is clamped in the holder provided for it. It is to be observed that the ammeter and detector are first to be taken out of circuit, and the switch, *B*, set on the first contact. The detector, *D*, and the telephone, *T*, are in series with each other, and in parallel with the condenser *C*. In using them the switch, *B*, must be set on the fourth contact.

The buzzer, *S*, with its accessories, is connected directly to terminals of the condenser, and in parallel with it. In using it, the switch, *B*, is set on the fourth contact. If Morse signals are used, the second contact is to be used.

As an accessory, there is furnished a support made of pliable leather, with a foot-plate and clamps upon which the inductance coil may be fastened in any desired position with relation to the circuit being measured.

## CHAPTER III

## USES OF WAVE METERS

### MEASUREMENT OF WAVE LENGTHS

### The Wave Meter Used as a Receiving Set

**General.**—The receptor loop, or inductance, of whatever form of wave meter is used, is, in general, brought in the vicinity of the inductance of the circuit being investigated and so that the lines of force thread through both inductances, the coil being held in the hand, or placed on its stand, if one is provided, so as to be conveniently movable with respect to the circuit to be measured. The most favorable position for the receptor coil of the wave meter must be determined by experiment. The convenience of the long flexible connection between the receptor coil of the Telefunken wave meters and box containing the condenser will be appreciated by those who attempt to measure the wave length of stations, where the helix is attached to the ceiling. The difficulty of holding the Pierce wave meter, the receptor loop of which is directly attached to the box containing the condenser, in the vicinity of a helix so placed, and operating the wave meter at the same time, will be appreciated by those who try it. If, however, a detector and telephone receiver, connected unilaterally (Fig. 7), be used as the current-indicating device, no difficulty will be experienced, since the meter can then be used yards away from the circuit being measured.

Using hot-wire ammeter, or thermo-element and galvanometer (see Figs. 4 and 5) as a detector, the reading of the ammeter or galvanometer will increase until the correct position of the pointer over the scale of wave lengths, together with the proper inductance coil, has been ascertained. The reading will increase to a maximum, and then become noticeably smaller again. Resonance corresponds to the highest reading of the instrument. The wave length corresponding thereto is read directly from the wave meter, calculated from tables, or read directly from curves of wave lengths provided with the instrument.

The coupling between the oscillatory circuit being measured and the receptor loop of the wave meter should not be any greater than necessary to get a readable deflection on the hot-wire instrument or galvanometer, for the resonance position. Otherwise, the instrument or the thermo-junction may be injured. In any case, no matter what form of resonance-indicating device may be used, the coupling ought to be as loose as possible, in order to avoid any back influence upon the exciting circuit, the frequency of which would be affected by too close coupling.

**Measurement with Helium Tube.**—The helium tube is connected to the terminals of the condenser of the wave meter. By changing the position of the condenser pointer the helium tube is brought to a glow, when, by approach to the resonance position, the voltage across the condenser reaches the value necessary to make the tube glow. If the helium tube lights up during too great a range of the condenser pointer, it is a sign that the wave meter is coupled too closely to the exciting cricuit. The receptor loop, or flat coil, should then be drawn away from the exciting circuit until the helium tube glows during only a very short movement of the pointer of the condenser.

**Measurement with Telephone and Detector, or Galvanometer and Detector.**—In consequence of the great sensibility of either of these arrangements, the coupling between the exciting circuit and the wave meter must be very loose. The inductance of the wave meter must be held distinctly farther away from the exciting circuit with this arrangement than is possible in the former cases. This device is ordinarily used many yards away from the circuit being measured.

## CHAPTER IV

### TUNING THE SENDING STATION

Disconnect the sending condenser, as shown in Fig. 18, and connect the lower end of the helix through the spark gap to ground. The secondary of the transformer is connected to the spark gap. The wave meter, *W*, is brought near the helix, and loosely coupled to it. The antenna is connected by a clip contact to some particular number of turns of the helix, and the sending key is depressed, making long dashes and producing a spark at the gap. This sets up oscillations in the antenna circuit, and the

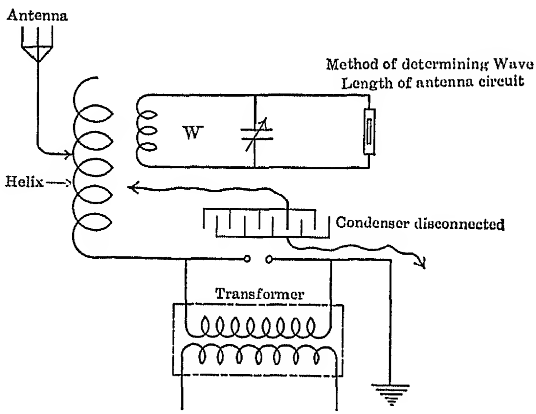



Fig. 18.

wave meter is adjusted to resonance with the exciting circuit. The wave length is read, and, with the corresponding number of turns of helix, is entered in a table. The spark gap, during these measurements, should ordinarily be used with the smallest sparking distance that can be used without maintaining an arc rather than a spark. The clip contact is now moved to another point on the helix, thus putting more or less inductance in the circuit, and the wave length is again determined and entered, with the number of turns of helix, in the table. It is well to start with all the turns of helix in series with the antenna, spark

gap and ground, and gradually reduce the number, one turn at a time, until no turns remain, and there is nothing in the circuit but the antenna, spark gap and ground. In measuring the aerial of a quenched spark station, an ordinary Marconi gap should be used instead of the quenched gap.

It will be found a trifle difficult at first trial to measure the wave length of the aerial when no turns of helix are included, except when the detector and telephone are used as a detecting device. The wave meter will have to be brought rather close to a half-turn of the wire leading to aerial or ground, if the helium tube is used, since it is not nearly as sensitive as the hot-wire ammeter, or the telephone and detector, as a receiving device. When these are used the coupling with the half-turn

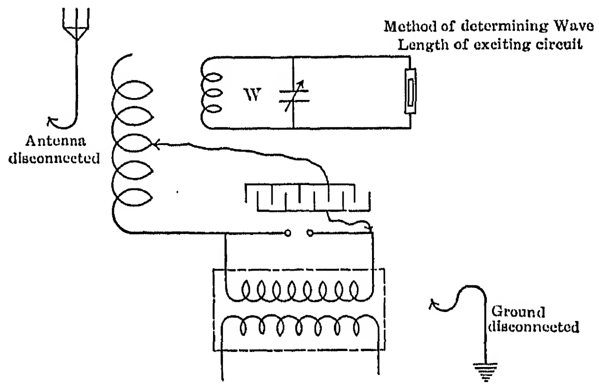



FIG. 19.

in the aerial wire can be made very loose. This wave length of the circuit, containing only the antenna, spark gap and ground, is called the natural wave length of the aerial. The natural period of the aerial is the time necessary for one complete oscillation in this aerial system, without any turns of helix, and is measured in microseconds. It should not, as is frequently done by some wireless experts, be confounded with the natural wave length, which is measured in meters.

From the table of wave lengths just formed, the results are plotted to a convenient scale, and give a curve like that marked, "Antenna Circuit," Fig. 20.

The condenser circuit is then measured in the same manner. In this case the antenna and ground (see Fig. 19) are disconnected;

and the condenser circuit, with the spark gap in series, is connected with various numbers of turns of the helix, and the wave length for each number of turns is determined, and a curve of wave lengths against turns is plotted. The curve for this case is put on the same sheet with the antenna observations, and marked "Exciting Circuit," Fig. 20.

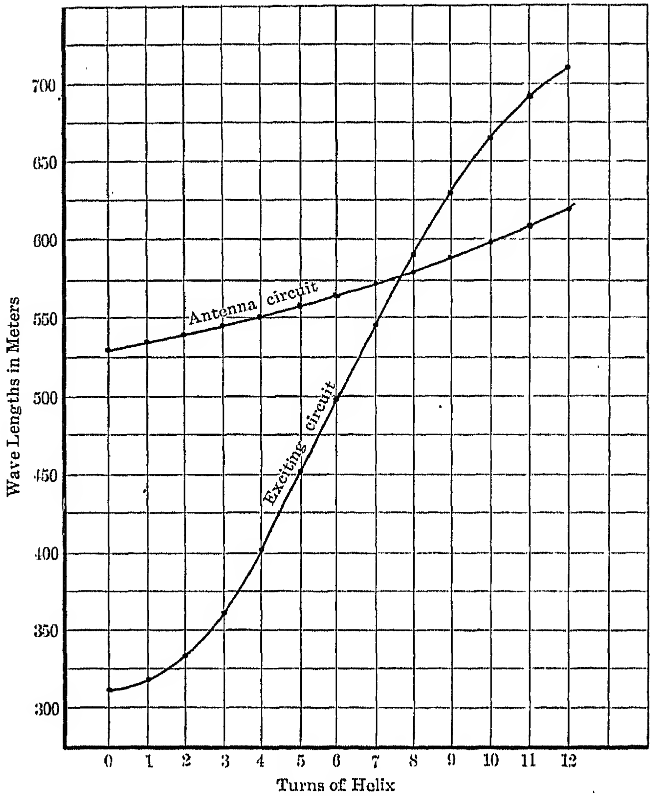



Fig. 20.—Tuning curves of sending station.

By a reference to these curves we can now obtain the number of turns required either in the condenser circuit, or in the antenna circuit, to produce a given wave length.

It is to be noted that the tuning curve thus found for the exciting circuit, is correct only when the capacity of the sending condenser remains the same as when the measurements of the

exciting circuit were made. Hence it is well to note what the capacity is at this time.

To illustrate the above process of tuning with the wave meter, let it be required, at the station for which the curves in Fig. 20 were plotted, to tune both exciting and antenna circuit to 580 meters.

From Fig. 20 it is seen that to get this wave length in the exciting circuit, one must use 8 turns of the helix, and to have the same wave length in the antenna circuit, when alone, one must use in this circuit $9\frac{1}{4}$ turns. Hence, if we connect the condenser and

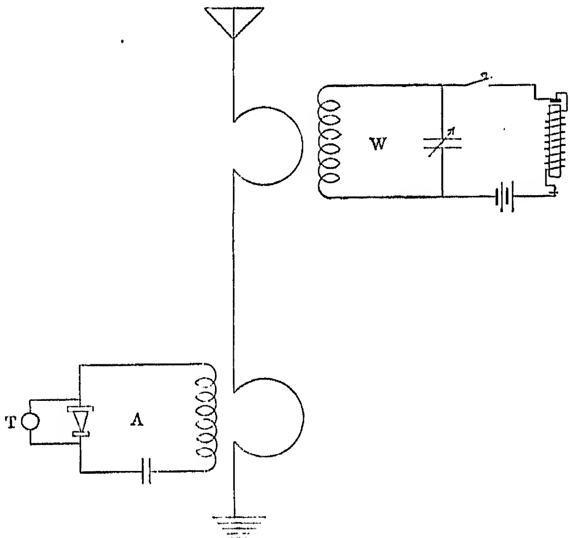



FIG. 21.

spark gap leads about 8 turns of helix, and the antenna and ground leads about $9\frac{1}{4}$ turns of helix, we shall have the two circuits in resonance, and powerful oscillations will be induced in the antenna, but there may be two, or only one resultant wave, sent out by the station, depending upon how closely, or how loosely, the two circuits are coupled. The question of coupling will be referred to later.

Another method of measuring the wave length of the antenna alone is as follows:

The antenna is excited by using a buzzer in circuit with the coupling turns of the exciting circuit, and the wave measured

by the wave meter, using the telephone as the indicating device. Also, the wave meter may be used as an oscillator, and induce oscillations in the antenna by being coupled therewith. An aperiodic circuit containing the detector and telephone, and connected inductively to the antenna (Fig. 21), will show when resonance is obtained, and the wave length determined from the position of the wave meter pointer.

**Measurement of the Wave Lengths of the Coupled System.**—As stated above, the open and closed oscillatory circuits of the sending apparatus, or, as they have heretofore been called in this paper, the "antenna" and "exciting" circuits, if coupled either directly, Fig. 22, or inductively, to each other, emit either one or two waves of different lengths, even if they have both been previously tuned to the same wave length.

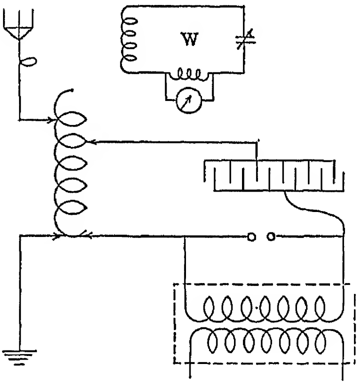
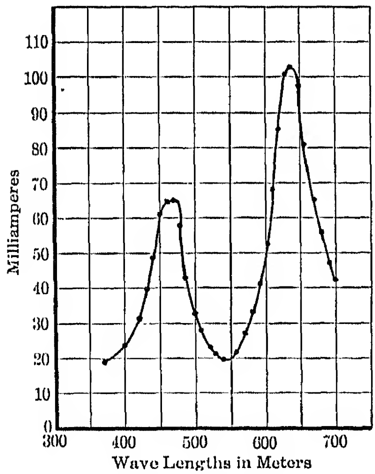



FIG. 22.—Measurement of radiated wave lengths of coupled circuits.

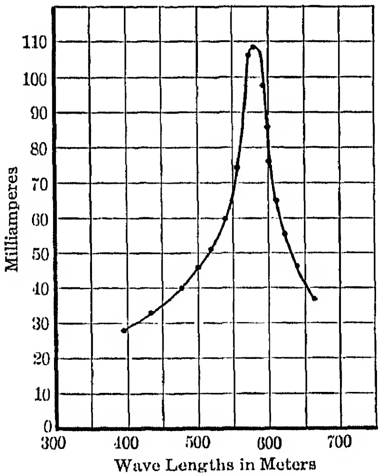
The measurement of the radiated wave or waves of a coupled system is shown in Fig. 22. The wave meter *W* is brought near a single small turn in the antenna lead of the station and the receptor loop placed so that it is parallel to this loop, and at sufficient distance from it, so that the wave meter circuit will not react upon the sending set. For a correct measurement of the radiated waves it is essential that the wave meter be operated only by the currents in the open circuit. The correct position for the wave meter with reference to the exciting, or closed circuit, is found when, upon the open circuit being uncoupled from the closed circuit, the wave meter is found to be unaffected by the closed circuit. Special emphasis is laid upon this correct method by the Department of Commerce in its instructions to Radio Inspectors, who are concerned only with the radiated waves. The key is then closed for a long dash and the pointer of the wave meter moved over the graduated scale until resonance is indicated by the indicating device used. This will generally be the longer wave, or "upper hump," since in stations so coupled that they send out two waves, the longer wave usually

contains the most energy, and is most easily found with the wave meter. To locate the short wave, or "lower hump" it may be necessary to bring the wave meter inductance closer to the antenna loop than before. The two humps of closely coupled circuits can usually be shown with the helium tube, but as this necessitates close coupling of the wave meter with the exciting circuit, errors in measurement may result. The telephone and detector is a far more accurate indicator for locating the two humps, since very loose coupling of wave meter and exciting




Close coupling.

Fig. 23.




Loose coupling.

Fig. 24.

Figs. 23 and 24.—Resonance curves.

circuit can be used. The dynamometer telephone of the Pierce wave meter also gives good results in this respect.

A far more instructive measurement of the two wave lengths may be made if a hot-wire ammeter or wattmeter, a thermo-element and galvanometer, or a detector and galvanometer, are at hand, since the different currents in the wave meter, for different settings of the condenser pointer can then be plotted and a curve obtained showing whether the station is sending out one or two waves, and at exactly what wave lengths the two resonance points are obtained. Figs. 23 and 24 are curves obtained by this process.

It was decided that the station above mentioned, would be

tuned to 580 meters. From the curves (Fig. 20), it was seen that to do this required $9\frac{1}{4}$ turns of helix in the antenna circuit, and eight turns in the exciting circuit. Then these turns were put in circuit as stated, and the circuits were coupled as closely as possible; *i.e.*, so that the 8 turns of the exciting circuit were common to the $9\frac{1}{4}$ turns of the antenna circuit. The wave meter, with hot-wire ammeter in circuit, as in Fig. 4, or with a shunted hot-wire wattmeter as shown in Fig. 25, instead of a helium tube, was then brought near a single small turn taken in the antenna lead (Fig. 22) above the helix of the station, and while the key was depressed, the hot-wire ammeter was watched as the pointer of the condenser was turned over the whole scale, in order to determine roughly where the position of resonance which would give the greatest current in the ammeter might be. This precaution is taken to avoid injuring the hot-wire meter.

The wave meter should not be so near the loop that the pointer of the hot-wire meter will run off the scale when resonance is reached. The dash made by the sending key should be long, and the variable condenser moved very slowly, as all hot-wire instruments work very slowly, and an error in the measurement of the current in the wave meter circuit may result from haste.

**Resonance Curves.**—Plotting ammeter or wattmeter readings as ordinates and those of condenser degrees as abscissæ, we get what is called a resonance curve (Fig. 23). If wattmeter readings are used, the ordinates plotted would be values of $I^2$, instead of $I$ or milliamperes, as shown in this figure. The two humps due to closely coupling the antenna and exciting circuits of the station are evident.

Though we tuned both antenna and exciting circuits to 580 meters, we find that the station is now sending out two waves, one longer, and one shorter than 580 meters. One measures 640 meters and the other 470 meters. In this case all the turns of the condenser circuit were included in those of the aerial circuit, and the circuits were coupled as closely as possible. Figure 24 shows a resonance curve obtained when the same circuits were loosely coupled, *i.e.*, had no turns in common, though each circuit had the same wave length as before. Only one hump is observed. Its maximum ordinate corresponds to practically the same wave length as that to which both circuits were originally tuned, viz., 580 meters.

A word of caution may well be given regarding the intensity

of the humps. They are not to be taken as having energy proportional to wave meter indications.

If a series of resonance curves is plotted, the coupling between the circuits being changed slightly for each succeeding curve, the evolution of the single hump from the double hump can easily be traced.

In measuring the natural wave length and securing tuning curves of a station employing the quenched spark system of excitation, the quenched spark gap must be replaced by an ordinary spark gap for the purpose of measurement. When measuring the closed oscillatory circuit of quenched spark transmitters having variometers in circuit, the power applied to the primary during the measurements should be reduced as much as possible, to avoid puncturing the variometer coils.

**Calculation of the Percentage of Coupling of a Coupled System.**—As stated before, when two circuits are tuned to a common wave length $\lambda$, called the basic wave length, and coupled together, unless the coupling is extremely loose, there result two wave lengths, $\lambda_1$ and $\lambda_2$, one of which is greater than the basic wave $\lambda$, and the other less.

While loosening up the coupling has the distinct advantage of allowing us to send out practically a single-valued wave length, nevertheless we are obliged to take into consideration the slight loss in the amount of energy transferred to the antenna circuit, due to the looseness of the coupling. In practice it is customary to so choose the coupling that, on the one hand, the energy received is sufficiently great; on the other hand, that the two resulting waves are not too far apart.

The coupling between the circuits is, ordinarily, expressed as a per cent., and is obtained by the following formula, after we have found, by measurement with the wave meter, the values, $\lambda$, to which both circuits were tuned; $\lambda_1$, the longer of the two resulting waves, and $\lambda_2$ the shorter:

$$K = \frac{\lambda_1 - \lambda_2}{\lambda} \times 100$$

Thus, in Fig. 23, we obtain the values of $\lambda$, $\lambda_1$, and $\lambda_2$, as 580, 640 and 470, respectively. The percentage of coupling in this case is—

$$K = \frac{640 - 470}{580} \times 100 = 29.3 \text{ per cent}$$

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The percentage of coupling found by the above method should not be confounded with the term Coefficient of Coupling, sometimes indicated by the letter $\tau$.

The value of $\tau$ is found from the equation—

$$\tau=\sqrt{\frac{M^2}{L_p L_s}}$$

where $M$ = the mutual inductance between the two circuits,

$L_p$ = self-inductance of the exciting circuit, and,

$L_s$ = self-inductance of the antenna circuit.

It is evident that these quantities are difficult to measure accurately in the case of the sending apparatus, so that, instead of finding the Coefficient of Coupling, we usually find the percentage of coupling of the sending station as outlined above.

While in practice it is usually the custom to measure the percentage of coupling, it is practically as easy to determine the Coefficient of Coupling, if, instead of using the equation given above for finding the value of $\tau$, we measure with the wave meter the basic wave length $\lambda$, and the resultant wave lengths, $\lambda$, and $\lambda_2$, and find $\tau$ by substituting these values in either of the derived formulæ:

$$\tau=\frac{\lambda_1{}^2}{\lambda^2}-1, \text{ or } \frac{\lambda_2{}^2}{\lambda^2}+1$$

If we substitute in either of these last equations the values used for $\lambda_1$ and $\lambda$, or $\lambda_2$ and $\lambda$, in the solution of the equation previously given for the percentage of coupling, it will be seen that the values of $\tau$ and $K$ are not identical, or the coefficient of coupling is not the same as the percentage of coupling, though the average value of $\tau$ found by solving both the above derived formulæ will closely approximate that found by the practical method of finding $K$ as given above.

## CHAPTER V

### MEASUREMENT OF DAMPING AND LOGARITHMIC DECREMENT

Since the passage of the Act to Regulate Radiocommunication in the United States, every sending station is required to be so adjusted that the logarithmic decrement per whole oscillation of the coupled circuits of the transmitter shall not be greater than an amount fixed by law; hence it is important that a practical method of measuring the logarithmic decrement be understood and practised by all persons responsible for the operation of radio stations to which the law applies.

A definition of damping and logarithmic decrement has been given among the definitions in the earlier part of this book. (*Cf.* page 2.)

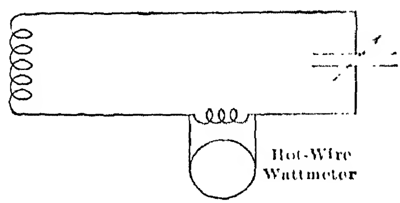


FIG. 25.

It is assumed that the oscillations in a train are practically exhausted when the last oscillation is not more than 1 per cent. of the initial one. Fleming has shown that the number of complete oscillations, $M$, in a train is given by the rule—

$$M=\frac{4.605+\delta}{\delta}$$

The quantity $\delta$ is the logarithm of the ratio of two successive oscillations in the same direction to one another, or, 2.303 times the ordinary logarithm to the base 10 of the same ratio. In other words, it is the logarithmic decrement per whole oscillation, and in accordance with the Act passed by Congress, this decrement $\delta$, shall not have a value greater than 0.2 "when measured with a sensitive wave meter."

The very simple method of measuring the decrement of a transmitter with the Marconi Decremeter, an instrument designed to measure this quantity directly, will not be given

here, as full directions accompany the instrument when furnished by the manufacturer. It may be well to state here, for the benefit of amateurs and other experimenters, that an instrument of the Decremeter pattern cannot be constructed from data given in magazines with any hope of having it correctly calibrated unless it be compared with some standard. The wave meter method here given, while it takes a little longer, will in general prove more satisfactory, since it can be used with practically any wave meter, and the results can be depended upon.

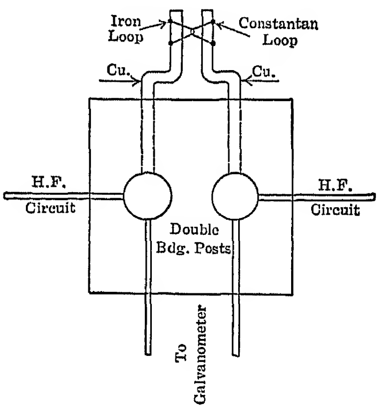


FIG. 26.—Iron-constantan thermo-element.

In order that a wave meter may be used to measure the damping, it is necessary to provide for insertion in the wave meter circuit, either a thermoammeter of the Duddell type reading from about 0 to 100 milliamperes, and having a very low resistance, preferably not more than one ohm, or a thermo-element of similar resistance and a galvanometer (Fig. 5), such as a single pivot Paul galvanometer, having a comparatively low resistance, or, what is by far the most practical method, and the one which has the advantage of giving the wave meter a smaller damping than the other methods, a hot-wire wattmeter properly shunted, or inductively coupled to the wave meter circuit (Fig. 25) should be used.

The thermo-element necessary for use with the galvanometer can be made in various ways, the essential point in the construction to be remembered being that the element must have a resistance of not over one ohm.

A simple form of thermo-element can be made as follows:

Two heavy copper wire leads are brought through a block of hard rubber of convenient size and soldered to double binding posts on the block for the purpose of making connection with the wave meter circuit. (See Fig. 26.) The same binding posts serve to connect the thermo-element to the galvanometer.

The copper wires project from the base as shown and are

brought up side by side and about 5 mm. apart. A short piece of fine iron wire in the form of a V or loop is soldered, as shown in the drawing, to one of the copper wires, and a similar loop of fine constantan wire, about 0.02 mm. in diameter, looped through and touching the iron wire, is soldered to the other copper wire. The length of the loops of iron and constantan wires, and the degree of tension with which one loop is drawn against the other will have to be determined by experiment, as the resistance of the element is measured on a slide-wire bridge, or other form of resistance measuring instrument. The resistance of the completed element should not be greater than one ohm.

Any other form of thermo-element may be used for damping measurements provided the resis mce is not above one ohm.

Such elements as that described above, on account of the nature of their construction, cannot be calibrated by means of direct currents, but may be compared, at least over the range of the larger high frequency currents with a sensitive hot-wire meter in the same circuit with it, *e.g.*, in a wave meter circuit; the current received by the wave meter when coupled to an oscillatory sending circuit, being varied by changing the position of the pointer of the wave meter, thus producing different values of the current in the wave meter and thermo-element galvanometer, the current directly read on the hot-wire ammeter being the current producing the corresponding deflection of the thermo-element galvanometer. Squaring the values of the currents read on the hot-wire meter when the thermo-element and galvanometer are in circuit, we then plot a curve, the abscissæ of which represent the scale readings of the galvanometer, and the ordinates, the square of the values of the current in the circuit. Hence, if we subsequently pass oscillations through the thermo-element, the reading of the galvanometer enables us to determine the value ($I^2$) of these oscillations at once.

To measure the damping of any circuit it will be necessary to open the circuit of the ordinary wave meter and insert in it the thermo-element and its galvanometer. Some wave meters still in use are not primarily intended for making damping measurements, so no binding posts may be found available for the insertion of the thermo-element, and other means will have to be improvised. In the Pierce instrument, the element may be inserted in series with the dynamometer telephone, or, better

still, the telephone may be omitted and the wave meter recalibrated.

**Measurement of Damping of a Closed Oscillatory Circuit.**—The wave meter, with thermo-element and its galvanometer in circuit, as in Fig. 5, is coupled with the oscillatory circuit to be measured, and a resonance curve may be obtained by plotting the readings $I^2$ corresponding to the various galvanometer deflections observed for various values of wave length obtained from the readings of the wave meter; the values of $I^2$ being plotted as ordinates, and wave lengths as abscissæ. Fig. 27 shows such a curve. (If a wattmeter be used instead of a

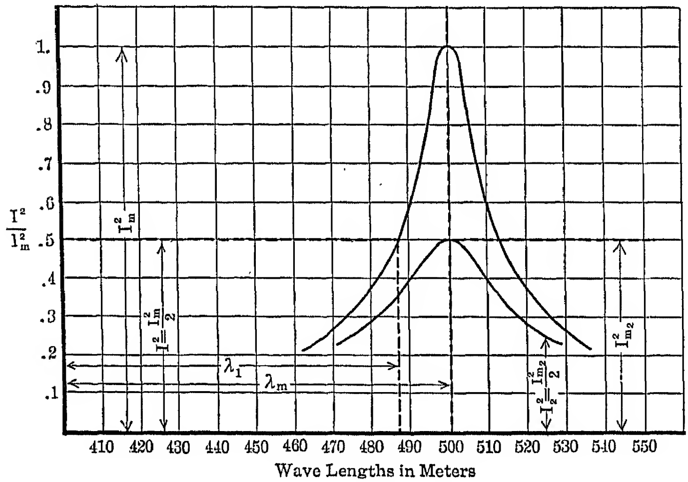


FIG. 27.

thermo-element and galvanometer note that the readings of the instrument do *not* have to be squared as the readings are themselves the squares of the current.)

It will be seen that the readings of the galvanometer increase with the wave lengths, until a maximum $I^2{}_m$ is reached corresponding to a wave length, $\lambda_m$. Then after passing the maximum value of the current, the readings fall off in value as we depart further from exact resonance.

Let $I^2{}_m$ be the square of the current in the wave meter read from the calibration curve of the galvanometer corresponding to the wave length $\lambda_m$, when exact resonance is obtained, and let $I^2$ be the square of the current in the circuit corresponding

to any other wave length $\lambda_1$. Now the oscillation circuit under test has a certain decrement $\delta_1$, and the wave meter itself has a certain decrement $\delta_2$.

V. Bjerknes has shown that the following relation holds good between the decrements of the two circuits, and the wave lengths $\lambda_m$ and $\lambda_1$ (when the currents $I^2_m$ and $I^2$ were obtained), provided that $\lambda_m$ and $\lambda_1$ do not differ from one another by more than say 5 per cent.; and that $\lambda_1$ is less in value than $\lambda_m$.

$$\delta_1+\delta_2=2\pi\left(1-\frac{\lambda_1}{\lambda_m}\right)\sqrt{\frac{I^2}{I^2_m-I^2}}$$

This formula is true only provided $\delta_2$ is small in comparison with $\delta_1$.

If it be desired to use the condenser readings of the wave meter, instead of the wave lengths, as is commonly done by radio engineers in this country, the formula becomes,

$$\delta_1+\delta_2=\pi\frac{C_m-C_1}{C_m}\sqrt{\frac{I^2}{I^2_m-I^2}}$$

where $C_m$ and $C_1$ are the capacities of the wave meter condenser corresponding to $\lambda_m$ and $\lambda_1$ in the first equation. Condenser scale readings in degrees may also be used, as explained later.

In plotting the resonance curve described above, it is usual to take $I^2_m$ as unity and $I^2$ as a decimal part of $I^2_m$.

The formula for the damping given above becomes greatly simplified for practical purposes, and gives accurate enough results, if, instead of plotting the complete resonance curve, we change the variable condenser so that for a wave length $\lambda_1$ the galvanometer deflection will have fallen to $\frac{1}{2}$ what it was at the resonance position, *i.e.*, so that $I^2=\frac{1}{2}\,I^2_m$. (If the current is read with a hot-wire instrument of not more than one-ohm resistance reading directly in amperes, then the reading of the meter corresponding to $\lambda_1$ should be $\frac{1}{1.414}$ of that corresponding to $\lambda_m$, since $1.414=\sqrt{2}$). Then in the above equation the quantity under the radical becomes unity and the formula takes the simplified form:

$$\delta_1+\delta_2=2\pi\left(1-\frac{\lambda_1}{\lambda_m}\right)\cdot=\pi\frac{C_m-C_1}{C_m}$$

Since the resonance curve is not quite symmetrical with respect to its maximum ordinate it is best to determine the values of the wave length $\lambda_1$, lying on either side of the maximum ordinate which correspond to $\frac{1}{2}I^2{}_m$, and to take the mean of these values to be put into the above formula. Using capacity readings instead of wave lengths the mean value is given by the formula

$$\delta_1+\delta_2=\frac{\pi}{2}\,\frac{C_2-C_1}{C_m}$$

where $C_2$ and $C_1$ are values found on either side of $C_m$, when the wattmeter, ammeter, or galvanometer readings fall from $I^2$ to $\frac{I^2}{2}$. This is the most practical method, and most direct.

The measurement gives the sum of the dampings of the wave meter and of the oscillatory circuit being measured. To get the damping $\delta_1$, of the latter circuit alone, it will be necessary to subtract the wave meter damping, $\delta_2$, from the result obtained.

## EXAMPLE: USING WAVE METER WITH GALVANOMETER AND THERMO-ELEMENT (FIG. 5)

Galvanometer deflections are proportional to $I^2$, but actual currents are not to be measured.

Formula used $\delta_1+\delta_2=2\pi\left(1-\frac{\lambda_1}{\lambda_m}\right)$ where $\lambda_m$ is greater than $\lambda_1$.

Let $D$ = initial deflection of galvanometer obtained when $\lambda_m$ is reading of wave meter for resonance.

### EXAMPLE

Suppose $D=100$ scale divisions when $\lambda_m=500$ meters. Reduce scale reading of galvanometer to $\frac{1}{2}D=50$ scale divisions in this case, by turning condenser handle of wave meter.

Read from wave meter scale the wave length $\lambda_1=488$ m. corresponding to this deflection on galvanometer.

Substituting values in the formula above, the joint damping

$$\delta_1+\delta_2=6.2832\left(1-\frac{488}{500}\right)=0.1508$$

For accuracy the pointer should also be brought from the resonance position to a wave length greater than $\lambda_m$ which will

also give a deflection $\frac{1}{2}D$ and the values of $\lambda_m$ and $\lambda_1$ so found substituted in the formula which becomes $\delta_1+\delta_2=2\pi\left(1-\frac{\lambda_m}{\lambda_1}\right)$ for this case.

The two values of $\delta_1+\delta_2$ thus found, should be averaged to get the mean value of the joint damping.

If $\delta_2$ = damping of the wave meter, is known, subtract this value from that just obtained, which gives value of the damping of the circuit measured. Thus if $\delta_2=0.0192$, we at once get $\delta_1=0.1508-0.0192=0.1316$ as the damping of the circuit being measured.

### DAMPING MEASUREMENT USING THERMOAMMETER (FIG. 4) INSTEAD OF GALVANOMETER

$$\text{Formula } \delta_1+\delta_2=2\pi\left(1-\frac{\lambda_1}{\lambda_m}\right).$$

Let $D$ = initial reading of the thermoammeter corresponding to $\lambda_m$.

Suppose $D$ = 100 milliamperes. $\lambda_m=500$ m.

Reduce scale reading on thermoammeter to the value $\frac{D}{1.414}=\frac{100}{1.414}=70.7$ milliamperes when $\lambda_1=488$.

$$\text{Then } \delta_1+\delta_2=6.2832\left(1-\frac{448}{500}\right)=0.1508.$$

The other value of $\delta_1+\delta_2$ would be found as with thermo-element and galvanometer, and the mean value of the damping determined. As before, knowing the value $\delta_2$, subtract it from the value just obtained to get the logarithmic decrement of the circuit measured.

### DAMPING MEASUREMENT USING HOT-WIRE WATTMETER

The wattmeter is connected to the wave meter as shown in Figs. 17 and 25. Condenser capacities, instead of wave lengths, are read from a curve or table of capacities made for the wave meter condenser showing the capacity corresponding to any degree reading of the scale. It is immaterial whether the capacity be recorded in centimeters or in microfarads. The watt-

meter readings are in watts, equal to $I^2R$, and are purely relative. Since special alloy wire is used in the construction of the wattmeter, $R$ does not change by heat within the range of the scale on the meter, hence the instrument may be considered as showing directly the values of $I^2$.

Formula

$$\delta_1+\delta_2=\frac{\pi}{2}\,\frac{C_2-C_1}{C_m}$$

Suppose the wattmeter reads 0.030 when $C_m=0.00120$ mfd. at resonance, and that $C_1=0.00118$ mfd. and $C_2=0.00123$ mfd. are the two values obtained after moving the condenser pointer to left and right of the resonance position, respectively, until

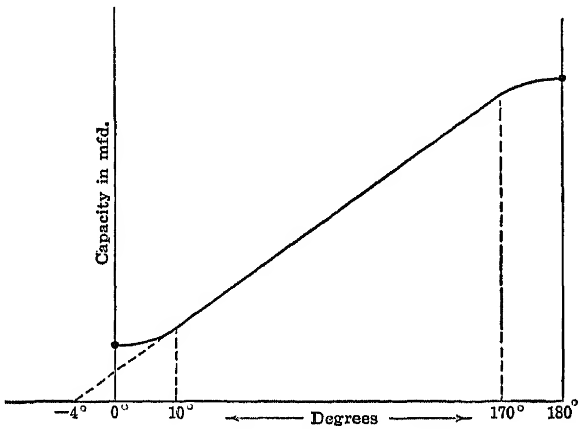


FIG. 28.

the wattmeter in each case reads one-half what it did at the resonance position, or 0.015.

Substituting in the formula we get

$$\delta_1+\delta_2=1.57\,\frac{0.00005}{0.00120}=0.0654$$

and knowing $\delta_2$ we at once get the logarithmic decrement of the circuit measured.

Radio engineers, in actual practice, use the condenser readings in degrees directly, provided the condenser of the wave meter has a straight line calibration. A condenser with plane

semi-circular plates will have a straight line for its calibration between approximately 10° and 170° as shown in Fig. 28, and, if the straight line be extended back of the capacity axis as shown, it will cut the other axis, or scale of degrees, at a point about 3°, 4°, or 5°, to the left of the origin, or zero; hence within the limits 10° and 170°, capacities will vary as the condenser readings in degrees, plus 3°, 4°, or 5°, as the case may be, depending upon the particular condenser used. This is the usual method, the value to be added, as +4°, generally being given with the calibration by the maker, as in the case of the E. G. W. meter of the Telefunken Co., where the value to be added is given as +4°.

Suppose we were to measure the logarithmic decrement by using condenser degrees, and that the condenser used had a calibration curve, which, if prolonged would strike, as in Fig. 28, a point 4° to the left of the $C$ axis.

Formula

$$\delta_1+\delta_2=\frac{\pi}{2}\,\frac{C°_2-C°_1}{C°_m+4°}$$

Suppose $C°_m=150.0°$, $C°_1=146.2°$, and $C°_2=154.8°$, and that these values are found, by reference to our calibration curve of capacities, to correspond to 0.00250, 0.00244, and 0.00258 microfarads, respectively.

Substituting

$$\delta_1+\delta_2=\frac{\pi}{2}\,\frac{154.8°-146.2°}{150.0°+4.0°}=\frac{\pi}{2}\,\frac{8.6°}{154.0°}=0.0876 \text{ or } 0.088-$$

If, instead of using condenser readings in the formula, we had used capacities the result would have been practically the same; for, substituting the capacity values we get

$$\delta_1+\delta_2=\frac{\pi}{2}\,\frac{C_2-C_1}{C_m}=\frac{\pi}{2}\,\frac{0.00258-0.00244}{0.00250}=0.088-$$

The method using condenser degrees is as accurate as that using capacities, and recommends itself as being the quickest of all methods for measuring the decrement.

The value of the self-damping, $\delta_2$, of the wave meter is not furnished by all makers of wave meters. For the E. G. W. meter of the Telefunken Co., the damping of the wave meter for the various spools is about as follows:

| | |
|---|---|
| Spool I | 0.046 |
| Spool II | 0.040 |
| Spool III | 0.024 |
| Spool IV | 0.023 |
| Spool V | 0.017 |
| Spool VI | 0.019 |

where spool I is for the shortest wave lengths and spool VI for the longest.

For exact measurement with any wave meter the self-damping of the wave meter must be determined by the method given below.

*It is absolutely necessary in the measurement of the damping to work with a constant coupling, and to take care that the energy in the primary circuit is as constant as possible.* If the coupling between the exciting circuit and the wave meter is too close, the damping will have too great a value. If there is any doubt as to whether the coupling was loose enough, measurements are made using two different couplings. If the smaller value is obtained with the looser coupling, then it is evident that the coupling was too close during the first measurement.

**Determination of the Self-damping of the Wave Meter.**— The sum of the dampings of both circuits $(\delta_1+\delta_2)$ having been found as stated above, a fine wire non-inductive resistance, $R$, Fig. 29, is inserted in the wave meter circuit and another measurement of the sum of the dampings of the exciting circuit and the wave meter is made, the position of the wave meter with reference to the exciting circuit being exactly the same as in the former measurement. After the insertion of the resistance the reading of the thermo-element galvanometer or of the wattmeter falls from $I^2_m$ to the value $I^2_{m2}$ at the resonance position previously found. In order to make the measurements sufficiently accurate it is necessary to put in so much resistance that $I^2_{m2}$ will become about $\frac{1}{2}\, I^2_m$ (Fig. 27).

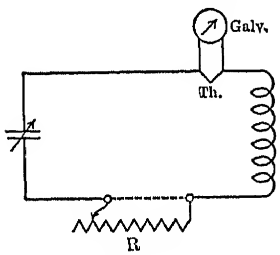

Fig. 29.

The damping of the wave meter has been increased by an amount $\delta'_2$, and the sum of the dampings now measured equals $(\delta_1+\delta_2+\delta'_2)$, instead of $(\delta_1+\delta_2)$ as before. The same method of procedure is followed for finding the sum $(\delta_1+\delta_2+\delta'_2)$ as was

used in finding $(\delta_1+\delta_2)$, *i.e.*, from the resonance position corresponding to $I^2_{m2}$ the current is reduced to $\frac{1}{2}I^2_{m2}$ by turning the handle of the wave meter, and the wave length or the capacity for the resonance position and that corresponding to the wave length $\lambda_2$ or the capacity $C_3$ is read from the scale when the current in the wave meter $I^2_2$ is equal to $\frac{1}{2}I^2_{m2}$ and the values are inserted in the formula,

$$(\delta_1+\delta_2+\delta'_2)=2\pi\left(1-\frac{\lambda_2}{\lambda_m}\right)=\pi\frac{C_m-C_3}{C_m}$$

where $\lambda_2$ and $\lambda_m$ are the wave lengths, or $C_3$ and $C_m$ the capacities found after insertion of resistance, $R$, in wave meter, $\lambda_m$ and $C_m$ being the same as before. Knowing the values of $(\delta_1+\delta_2)$ and of $(\delta_1+\delta_2+\delta_2)$, it is a simple matter to get $\delta'_2$, which is equal to the difference between these two sums.

In using capacities instead of wave lengths it is much more convenient to use the combined formula

$$(\delta_1+\delta_2+\delta'_2)=\frac{\pi}{2}\,\frac{C_4-C_3}{C_m}$$

where $C_3$ and $C_4$ are the capacity values found on either side of $C_m$, after the introduction of the resistance wire into the wave meter circuit, when the current is reduced from $I^2_{m2}$ to $\frac{1}{2}I^2_{m2}$.

If we put $X$ for $(\delta_1+\delta_2)$ and $X'$ for $(\delta_1+\delta_2+\delta'_2)$, the value of $\delta_2$ can be obtained from the following formula:

$$\delta_2=\frac{X'\delta'_2}{2X-X'}$$

and since $X=\delta_1+\delta_2$

$$X-\delta_2=\delta_1$$

Hence, substituting in this equation the value of $\delta_2$ found as above we arrive at the decrement of the circuit under test.

### EXAMPLE: TO FIND DAMPING OF THE WAVE METER

**Using Thermo-element and Galvanometer.**—Piece of resistance wire (about ten inches of No. 26 Climax), with sliding contact for varying length of wire used, is introduced into wave meter circuit. When this resistance wire is inserted in the wave meter circuit there must be no, or only a very short, free end to

this wire, as otherwise, if the sliding contact picks off only a small part of this wire a very serious error may sometimes be made. The wire can be shortened accordingly.

Wave meter pointer again set to value of $\lambda_m$ found in former example (500 m.), and left there.

While key is depressed, adjust sliding contact on resistance wire until galvanometer deflection is reduced to $\frac{1}{2}\ D=50$, in this case.

Having thus determined right amount of resistance wire, turn condenser pointer of wave meter until galvanometer shows deflection $\frac{1}{4}\ D=25$ in this case.

Read corresponding wave length $\lambda_2=486$ meters.

$$\text{Then } \delta_1+\delta_2+\delta'_2=2\pi\left(1-\frac{\lambda_2}{\lambda_m}\right)=6.2832\left(1-\frac{486}{500}\right)=.1664$$

$$\text{Let } \delta_1+\delta_2+\delta'_2=X'=.1664$$

$$\text{Average value} \qquad \delta_1+\delta_2=X=.1508$$

Then the difference $\delta'_2=0.0156=$ damping due to insertion of resistance wire. Damping of wave meter

$$=\delta_2=\frac{X'\delta'_2}{2X-X'}=\frac{0.1664\times0.0156}{(2\times0.1508)-0.1664}=0.0192$$

If this value of the damping has been carefully determined for the particular inductance of the wave meter used, it can be marked on the instrument for future reference, and, to simplify later damping measurements, the damping for each of the inductances of the wave meter should be determined in this manner.

**To Find Damping of Wave Meter Using Thermoammeter.**—Suppose $\lambda_m=500$ m. Set pointer at that reading. Resistance wire introduced into wave meter circuit, and adjusted so that current shown on ammeter falls to value $\frac{D}{1.414}=70.7$ milliamperes.

Leaving resistance unchanged, move wave meter pointer until current $\frac{D}{2}=50$ milliamperes is shown on ammeter. Then $\lambda_2$ is found to be equal to 486 meters.

Proceed as with thermo-element and galvanometer to find damping of wave meter by substitution of these values in formulæ.

**To Find Damping of the Wave Meter Using the Wattmeter.**—Let $C°_m$, as in the example before given, where the wattmeter was used to measure the damping, equal the scale reading of the condenser, in degrees, at the resonance position. This was found to be 150.0°. Set condenser pointer at that reading. Resistance wire is introduced into the wave meter circuit as described for thermo-element and galvanometer, and adjusted so that the energy shown on the wattmeter falls to one-half the former reading at resonance; in this case 0.015 watts.

Leaving the resistance unchanged, move the condenser pointer first to the right and then to the left of the resonance position, and note the readings of the condenser, $C°_4$ and $C°_3$, respectively, when the wattmeter reading in each case has fallen to one-half the reading for resonance with the resistance in circuit; in this case 0.0075 watts.

Suppose $C°_4 = 155.6°$ and $C°_3 = 145.35°$

Substituting in formula

$$(\delta_1+\delta_2+\delta'_2) = 1.57\,\frac{155.6° - 145.35°}{150.0° + 4°} = 0.1045$$

Proceeding as before described for thermo-element and galvanometer, by substituting in the formulæ given the values already found, we determine the damping of the wave meter, $\delta_2$, to be 0.024 for the coil used in this case.

If, instead of using condenser degrees, we use actual capacities, the formula used would be

$$(\delta_1+\delta_2+\delta'_2) = \frac{\pi}{2}\,\frac{C_4 - C_3}{C_m}$$

and $\delta_2$ would be found as described above.

While the method of using capacities instead of wave lengths has been given only in illustration of the method of making measurements of the decrement with a wave meter using a wattmeter for measuring the relative energy, it is evident that this simple capacity measurement can be just as easily used when a thermo-ammeter or a galvanometer and thermo-element are employed, not only for measuring the damping of any radiating circuit but of the wave meter itself, and it is recommended to the reader as the most practical method in every day use, and the shortest method with the exception of the direct measurement with a decremeter.

**Determination of the Resistance of the Spark Gap.**—If, in any case just cited, the inductance of the oscillatory circuit in centimeters is known, or can be measured, and the high frequency resistance, $R$, of the inductance can be calculated from the dimensions of the wire, it is possible, knowing the value of $\delta_1$, and the frequency $N$ corresponding to resonance, to calculate the resistance of the spark gap from the following formula:

$$r=\frac{2NL\delta_1}{10^9}-R$$

where $R$ and $r$ are measured in ohms.

**Determination of the Approximate Number of Complete Oscillations in a Wave Train before the Amplitude of the Oscillations Falls to 0.01 of the Maximum.**—Having found that the value of $\delta_1$ for the circuit in one case cited was 0.1316, from the formula

$$M=\frac{4.605+\delta_1}{\delta_1}=\frac{4.605+0.1316}{0.1316}=35$$

it is seen that each train comprised about 35 complete oscillations.

**Measurement of the Damping of a Coupled System.**—This is the ordinary case where it is necessary to determine the damping of a coupled system consisting of an antenna circuit and an exciting circuit which are tuned to the same period. If the system employs the ordinary gap, instead of the quenched spark gap, in the exciting circuit, and the coupling between the circuits is not very loose, there result two wave lengths, as before shown, one longer and the other shorter than the wave length to which each of the circuits was originally tuned. If these two wave lengths lie sufficiently far apart, the damping of each hump is measured separately by the method described for the measurement of the damping of a closed oscillatory circuit with spark gap, *except that the wave meter is coupled to the loop in the antenna lead above or below the antenna helix, and in a position not affected by the primary circuit,* as in measuring the radiated waves (Fig. 22). This precaution is particularly insisted upon by the Department of Commerce so as to avoid the possibility of a false measurement of the decrement due to the proximity of the exciting circuit.

No difficulty will be encountered in measuring coupled circuits where the coupling is extremely loose, or a quenched spark

is used in the exciting circuit, since there will be practically only one hump.

**To Reduce the Logarithmic Decrement of a Coupled System found to be Greater than the Legal Limit.**—Having measured the damping of the radiating circuits as coupled, and found it greater than 0.2 per complete oscillation, it is necessary to add inductance in order to decrease it or to loosen the coupling in order that the total resistance may be decreased. If it is not practicable to change the wave length, the aerial must be shortened to decrease its capacity while retaining the same wave length by adding inductance. Putting a condenser in series with the aerial produces the same effect, but is not considered the best practice, though it may well be used in low potential oscillating sets that require very close coupling. Such a condenser is sometimes used with good effect in certain wireless telephone transmitting sets.

**Method of Procedure in the Adjustment of the Sending Station to Comply with the Act to Regulate Radiocommunication Approved August 13, 1912.**—1. Tuning curves are made as described on pages 22 and 23.

2. If the station is restricted by law or order to the use of one definite sending wave length, say 600 meters, the number of turns necessary in antenna and exciting circuits to secure this wave length is taken from the tuning curves as described on page 25.

3. Plot a resonance curve using fairly loose coupling of circuits and note whether the energy in the smaller hump, if there are two humps, exceeds 10 per cent. of that in the larger; *i.e.*, if the value of $I^2$ calculated from the reading of the ammeter or read directly from the wattmeter in the wave meter circuit when in resonance with the peak of the smaller hump exceeds 10 per cent. of the maximum ordinate $I^2$ of the greater hump. If it does, the station is not using a "pure wave" as defined by the act to regulate radiocommunication, and the coupling must be loosened until this condition is fulfilled.

In making this measurement and that in paragraph 4, the wave meter should be coupled with a single loop above or below the antenna helix and in a position not affected by the primary circuit, but only by the radiating circuit (Fig. 22).

That this is the correct interpretation of the definition of "pure wave," and the correct method of determining when the station

is emitting a "pure wave," is the decision given to the author by the Department of Commerce and Labor, with the assent of the Director of the Bureau of Standards.

4. Having found from the resonance curve that the station is using a "pure wave," measure the damping of the radiating circuits and see if the decrement is greater than 0.2 per whole oscillation, the limit placed by law on all stations.

5. If the decrement is too great, reduce the coupling and measure again. Reducing the coupling will usually be found to be the only correction necessary, but if this should fail to produce desired results, make the changes outlined in the first paragraph on page 45.

6. Adjust the spark gap until the hot-wire meter in the antenna circuit shows the greatest radiation, all other adjustments remaining fixed.

7. The station is now adjusted in compliance with regulations, and orders are issued to permit no change in the adjustments, unless directed by higher authority, or required or permitted by regulations or by law.

**Where the Wave Length is not Restricted by Law or Official Order.**—Where the station is not restricted to a particular wave length, effort should be made to find the adjustments giving the greatest efficiency regardless of resulting wave length.

There is one best wave length for every station, and when that is determined, the greatest radiation is usually obtained.

The process of tuning the station for maximum efficiency, utilizing the best wave length for the station is as follows:

1. Make tuning curves of antenna and exciting circuits.

2. To determine which of the wave lengths lying within the limits of the curve marked "Antenna Circuit" will give the best radiation, it will be necessary to have a hot-wire meter in the antenna circuit for noting the radiation. (a) If the oscillatory circuits are direct-coupled, start by placing the lead from the spark gap on some turn near the middle of the helix, and to the same point attach the ground lead. Leaving these two leads fixed, move the other two, one to one side and the other to opposite side of the fixed leads, placing successively, one, two, three, etc., turns in the aerial circuit, and the corresponding number of turns in the exciting circuit required for resonance, as determined from the tuning curves, pressing the sending key and noting the reading of the hot-wire meter in the antenna, for each combina-

tion, and, by comparison, determining which wave length gives the greatest radiation.

It is to be noted that the coupling is always kept loose, and approximately the same throughout all these measurements. The combination giving greatest radiation under these conditions should be adopted as the best for the station, so far as wave length is concerned.

(b) If the oscillatory circuits are inductively coupled, start by placing one turn, two, three, etc., in succession in the aerial circuit, and the corresponding number of turns necessary for resonance, as determined from the tuning curves, in the exciting circuit; being careful to maintain a loose and constant coupling throughout, between the two inductances. As before, the greatest radiation shows the best wave length to use.

3. Having determined the best wave length in this manner, proceed with the adjustment of the station as outlined in paragraphs 3 to 7 of the preceding case, using this best wave length instead of the 600 meter wave length there mentioned.

# CHAPTER VI

## MEASUREMENT OF WAVE LENGTH OF THE RECEIVING STATION

**The Wave Meter as a Sending Set.**—The calibration of a receiving set is equally as important as the calibration of the transmitting apparatus, for the operator of a wireless station should know what different adjustments of his apparatus he must make to put his receiving set in resonance with any particular wave length in order to facilitate rapid "picking up" of widely differing wave lengths when desirable to do so.

The different adjustments of the various apparatus of his receiving set corresponding to any particular wave length he takes either from tuning curves, or from tables of adjustments prepared for the particular receiving set and antenna he is using, or, not being provided with these, and having a wave meter at hand, he starts the buzzer of the wave meter to work continuously, sets the wave meter pointer for the desired wave length, and bringing the receptor loop of the wave meter near the single turn taken in either antenna or ground lead (see Fig. 30), varies the adjustments of his receiving apparatus while he listens in with the usual telephone receivers of his receiving set, until he hears the maximum sound, when the adjustments of the various apparatus of the receiving set can be noted in a table opposite the wave length as indicated on the wave meter. Care must be taken not to have the buzzer so close as to act directly upon any part of the receiving set.

A wave meter used systematically upon a receiving set will afford an operator in the shortest time, a better knowledge of tuning than can be obtained in any other way. An operator who knows exactly what adjustments to make for a given wave length will at once pick up a station, which, he is told, will send with that wave length, whereas, the operator without knowledge of this sort, or data from which to secure it, may spend hours adjusting his receiving apparatus to every possible adjustment but the right one for the strange station he wants to hear.

The Telefunken buzzers as before stated have a key with which

Morse signals may be sent out from the wave meter. This appears to be about the quickest way to teach a new operator to operate a receiving set, for, an instructor can have the operator "listening in" on the receiving apparatus, and, placing the wave meter far enough away from the operator so that the buzzer note will be inaudible as a sound wave through the air, and coupling the wave meter inductance with a loop in the antenna lead, can send out Morse signals, using a wide range of wave lengths one after another, and, in each case, have the listening operator tune the receiving set for the proper reception of the signals. The action of the different elements of the receiving set will thus become apparent, and this practical work will be worth a great deal more than any amount of theoretical instruction that the operator can receive.

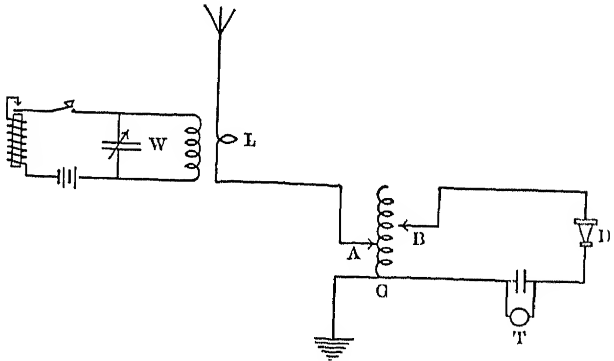


FIG. 30.

**Calibration of a Receiving Set Having a Double-slide Tuning Coil.**—The two bars (Fig. 30) on which the sliding contacts, *A* and *B*, move, should be divided into some convenient scale, say tenths of inches, which should be permanently marked thereon. Couple the coil of wave meter, *W*, with single loop, *L*, of antenna lead, and having started buzzer of wave meter going continuously, set pointer of wave meter at 350 meters, and listening in on telephone receivers, *T*, having adjusted detector, *D*, for sensitiveness, move sliders *A* and *B* away from *G* (the grounded end of tuning coil) until sound in telephone, *T*, is loudest. See if any re-adjustment of *B* will give any better signal. Having maximum sound in telephone receivers, make a table of adjustments like the following:

| Wave length meters | Antenna slider $A$ | Detector slider $B$ |
|---|---|---|
| 350 | 5 | 20 |
| 400 | 8 | 22 |

and so on; setting the wave meter for every 25 or 50 meters of the scale, in turn, and writing in above table the corresponding adjustments for every 25 or 50 meters until the $A$ slider reaches the end of the coil farthest from the grounded end $G$. It will be noted that there are many combinations of receiving adjustments which will give the same wave length. The proper one to use in actual work for best results will only be found by actual practice with the set. It will also be seen that the receiving set will always be in resonance with two or more waves at once, and it will easily be seen that such a tuning coil will always be liable to the greatest amount of interference, in other words, is not very selective.

**Calibration of Inductive Type Receiving Set Having an Untuned Secondary and Variable Primary.**—These inductive tuners are usually made so that the coupling between the primary and secondary coils can be varied, either by withdrawing the secondary from the primary, or, by rotating the secondary so that its turns may be moved through any angle from 0 to 90° with reference to the turns of the primary. The closest coupling, in the latter system, being obtained when the coils of the secondary are parallel to those of the primary. The number of turns in the primary may be varied either by a sliding contact moving on a rod parallel to the axis of the primary tube and touching the different turns, or, a switch arm, or pair of switch arms, moves over a series of switch points by means of which any desired number of turns of wire may be cut into the primary circuit. In the first case, where the bar with sliding contact is used, this bar should be graduated into tenths of inches, so that the exact position of the sliding contact can be determined by reference to this scale. In the case of the rotating switch arm moving over a series of switch points, the switch points should show the corresponding number of turns of primary cut in when the switch arms make contact with these points.

The secondary is usually provided with a number of taps for

cutting in, by means of a switch arm, different numbers of turns in the secondary circuit. These taps should be numbered with the number of turns for each button in order to distinguish them; or, better, they should be marked to indicate the range of wave lengths best adapted for the button in question.

In order to determine the coupling between primary and secondary used at any time, a scale of convenient graduations, say tenths of inches, should be placed so that an index carried by the moving secondary, will travel over the coupling scale and the coupling read from this scale. The zero of this scale should be so placed that when the secondary coil is completely out of the primary, the index will stand opposite this zero mark. The zero mark of

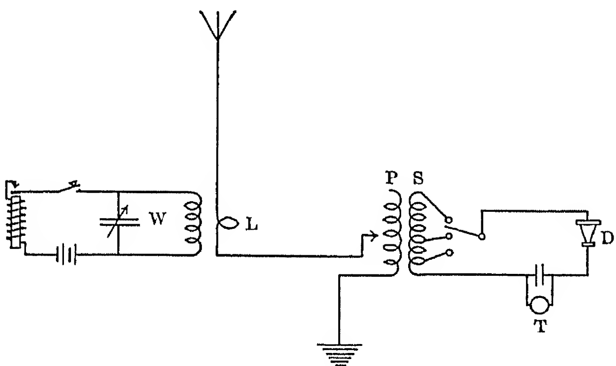


Fig. 31.

the coupling scale does not mean a zero coupling between the two circuits, which would be obtained only by separating the coils by a great distance. The greatest reading of the coupling scale will be had when the secondary is pushed completely into the primary.

To calibrate this receiving set, the operator "listens in" on set, using telephone receivers, $T$, adjusts his detector for sensitiveness, couples wave meter with loop in antenna lead (see Fig. 31), and starts buzzer going continuously. Setting the wave meter pointer at 300 meters he adjusts his primary turns, secondary turns, and coupling until he gets the strongest signals in his receiver from the wave meter. These are the adjustments necessary for 300 meters wave length. It will be noticed that there are many possible combinations of primary, secondary, and

coupling which will give 300 meters. The best adjustment, in order to avoid interference, will, as a rule, be the one affording the loosest possible coupling between the coils. Actual work with the set listening to stations having known sending wave lengths, will, in practice, determine the best combination of all three variable elements.

A table of wave lengths should be prepared as follows:

| Wave length meters | Primary | Secondary | Coupling |
|---|---|---|---|
| 300 | 7 | 90 | 20 |
| 325 | 8.5 | 90 | 22 |
| 350 | 10 | 90 | 24 |

and so forth, finding the best adjustments for every 25 or 50 meters increase in wave length, up to the limit of the tuner.

**Second Method.**—It will have been noticed that with untuned secondary, as in Fig. 31, the tuner is usually in tune with two wave lengths at the same time, one long and one short. Setting the primary at a given point, say 11 turns, and the secondary at 90 turns, if we examine the circuit with a wave meter, as we pull the secondary out of the primary, it will be found that *changing the coupling changes both the wave lengths to which the set is tuned.* With primary and secondary unchanged, take a series of readings with the wave meter for every five divisions of coupling scale. Plot data as shown in curves, Fig. 32. In this case, curves were plotted, first using the 90 turn secondary, then, the 210 turn secondary. The effect of changing the secondary turns is seen from the curves.

In order to cover practically all combinations of adjustments coming within the range of the tuner, so as to be able to read at once from the tuning curves the wave lengths for any given three adjustments, would require practically an infinite number of curves. In practice we would probably get curves for every 10 turns of primary, and for all values of coupling corresponding to each 10 turns, when using two or three different values of secondary. An examination of a tuner made in this manner with a wave meter, will give the greatest possible information about the method of operating it.

This method, however, involves considerable work, and, when finished, is hardly as satisfactory, for a permanent wireless sta-

tion, as that of having a wave meter always at hand, by means of which the receiving apparatus can be at once adjusted for any wave length desired, or the length of an incoming wave determined at once without reference to any calibration curve.

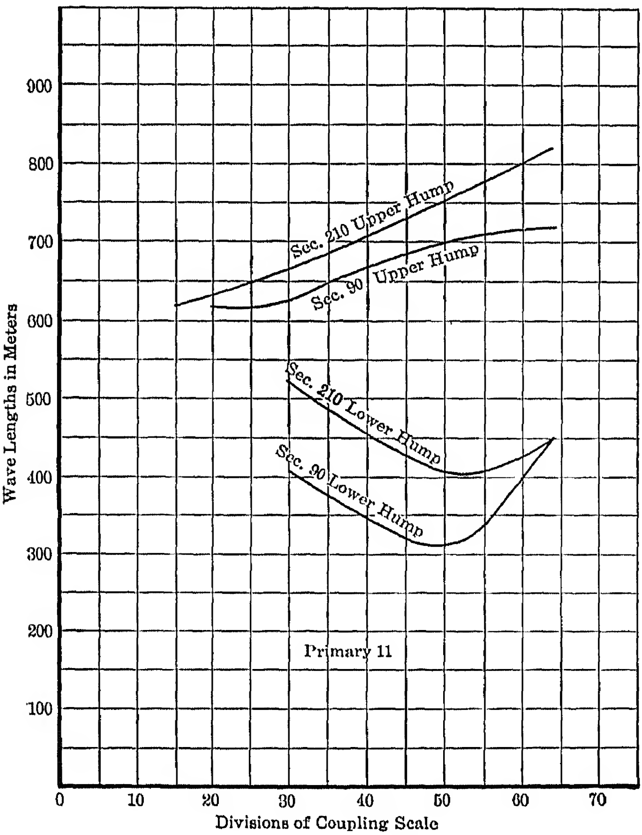


Fig. 32.

**Calibration of an Inductive Type Receiving Set with Variable Condenser in Series or Parallel, Secondary Untuned.**—The general method of setting up different wave lengths is the same as in the preceding cases. The tabulation now includes another variable element, the variable condenser.

Tabulate as follows:

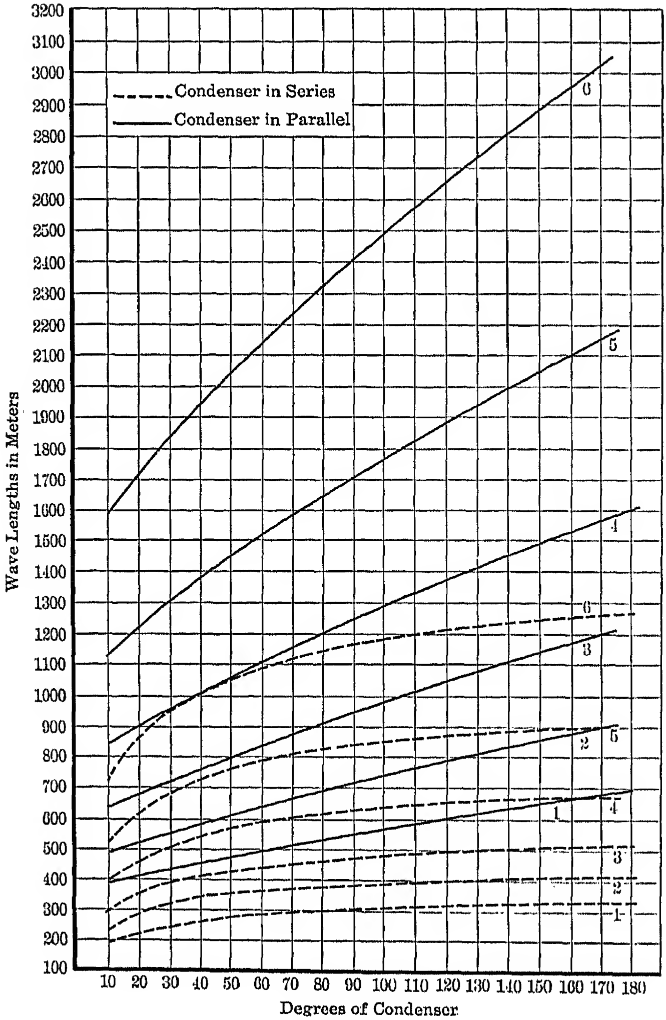


FIG. 33.—Coupling loose, but constant throughout. Primary consists of six steps of inductance numbered 1, 2, 3, 4, 5, and 6, respectively. Secondary circuit untuned.

| Wave length meters | Primary | Secondary | Coupling | Var. cond. series | Var. cond. parallel |
|---|---|---|---|---|---|
| 400 | 10 | 90 | 20 | 140° | .......... |
| 500 | 10 | 90 | 20 | 180° | .......... |

etc., for every 25 or 50 meters as desired.

If only one value of the coupling be used throughout the measurements, and only four or five values of primary used in connection with a variable condenser, the secondary circuit being aperiodic, a set of curves like that shown in Fig. 33 is obtained. These are the curves of the Telefunken 2 kw. wagon set purchased for use in the United States Signal Corps. It is seen how the wave lengths vary with the change of the condenser, the coupling, primary, and secondary, remaining unchanged.

In operating this receiving set, and in fact all inductively coupled receiving sets, the loosest possible coupling should always be used, and both circuits, as far as the variation of the secondary will permit, should be tuned, at this coupling, to the same wave length, *i.e.*, the wave length of the distant transmitter. If the coupling be changed, then both circuits, as far as practicable, should be retuned. Exact tuning of the secondary is usually impracticable unless its inductance is shunted with a variable condenser.

**Calibration of Inductive Type Receiving Set with Tuned Secondary.**—The object is to calibrate both circuits of the receiving set independently, so as to be able to set both of them for the same wave length, and, by using the loosest possible coupling, have the station tuned to but one wave length at a time, and by these means, not only avoid interference, but reduce the effects of static and atmospheric discharges to a minimum. This calibration is absolutely necessary if the receiving apparatus is to be used for reading signals from stations sending out sustained or practically undamped oscillations. A variable air condenser of about 0.002 mfd. maximum capacity is connected in parallel with the secondary, Fig. 35, and this circuit is tuned by varying the condenser.

**Calibration of the Antenna Circuit.**—Couple an untuned secondary circuit, as shown in Fig. 31, as loosely as possible with the primary, and then with wave meter set up waves of different lengths varying the primary or antenna circuit, and listening

for maximum sound in the telephone receivers at the resonance position, when the antenna is tuned to the same wave length as the wave meter.

Tabulate turns necessary for various wave lengths as follows:

| Wave length meters | Primary turns |
|---|---|
| 350 | 4 |
| 400 | 7 |
| 450 | 10 |
| 500 | 13 |

and so forth, up to the limit of the primary coil.

Another method, due to Professor Pierce, is shown in Fig. 34, where the primary is excited by a nearby wave meter with attached buzzer. A detector with telephone receiver in shunt is unilaterally connected to the primary circuit as shown. If the

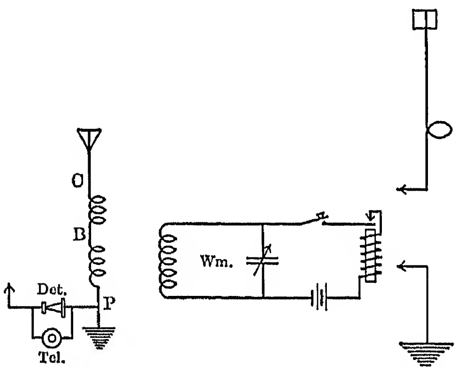


Fig. 34.—Calibration of primary, Pierce's method.

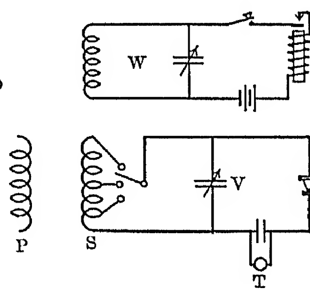


Fig. 35.—Calibration of secondary.

sound is too faint with detector attached as in diagram, move connection to *B* or *C*.

**Calibration of the Secondary Circuit.**—The antenna and ground are then disconnected from the primary, *P*, of tuner (Fig. 35). Secondary, *S*, to the terminals of which the variable condenser, *V*, is connected, is loosely coupled with wave meter, *W*, and different numbers of turns of secondary are cut in by the switch; and the number of degrees of condenser with a fixed value of secondary necessary for different values of wave lengths

determined by listening for maximum sound in telephone, *T*. The coupling between the wave meter and receiving set should be made so loose that the maximum sound occurs during only a slight change of the variable element. Tabulate results as follows:

DEGREES OF CONDENSER NECESSARY TO PRODUCE VARIOUS WAVE LENGTHS WITH DIFFERENT NUMBERS OF SECONDARY TURNS

| Wave length meters | 25 turns | 50 turns | 90 turns | 210 turns |
|---|---|---|---|---|
| 400 | 7.5° | ........... | ........... | ........... |
| 500 | 19° | 6.5° | ........... | ........... |
| 600 | 29° | 10° | ........... | ........... |
| 700 | 40.5° | 14° | ........... | ........... |
| 800 | 54.5° | 18° | 8° | ........... |
| 900 | 70° | 23.5° | 9.5° | ........... |
| 1000 | 82° | 29° | 12° | ........... |
| 1100 | ........... | 35° | 14.5° | ........... |
| 1200 | ........... | 42° | 17.5° | ........... |
| 1300 | ........... | 49° | 21.5° | ........... |
| 1400 | ........... | 57° | 25° | 7.5° |

These results may be plotted as curves, making a curve for each value of secondary inductance, and plotting wave lengths in meters as ordinates, and degrees of condenser scale as abscissæ.

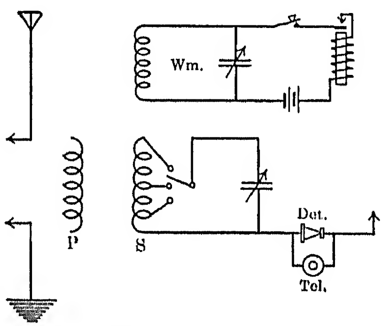


FIG. 36.—Calibration of secondary.

Another method is shown in Fig. 36. Connect a detector with telephone in parallel with it, unilaterally to the secondary, and excite the circuit with the wave meter.

**Measurement of Incoming Wave from a Distant Sending Station.**—Tune your own receiving apparatus as sharply as

possible to the incoming wave, getting the maximum strength of signals in your telephone receivers. The wave meter is coupled to the antenna as in Fig. 31, and when the signals from the distant station have ceased, the buzzer is started giving a continuous signal, and the inductance and capacity of the wave meter, *W*, are varied until the sound from the buzzer heard in the telephone of the receiving set is a maximum, when the wave meter is tuned to the receiving circuit.

The coupling is made so slight that the maximum sound occurs during only a slight change of the capacity. Then the reading of the wave meter is the wave length of the distant station.

If two wave lengths are observed due to close coupling of primary and secondary of the receiving apparatus, note both readings. To determine which is correct wave length, again tune to the distant station using a different amount of primary and a different coupling the second time. The correct reading will remain as before, but the false one will have a different value: or, better still, if using an inductively coupled set with variable primary and variable secondary, vary all the elements —primary inductance, secondary inductance, and condenser shunting secondary, and, when the set is tuned to the distant station with the loosest possible coupling, it will be found that it is in resonance with only one wave length, which is that of the distant station.

## CHAPTER VII

### MEASUREMENT OF CAPACITY AND INDUCTANCE

**Capacity of a Condenser by the Substitution Method.**—This supposes the possession of a calibrated, variable condenser.

A closed oscillatory circuit is made with any desired inductance *L* (see Fig. 37), and the unknown capacity *Cx*. Then an aperi-

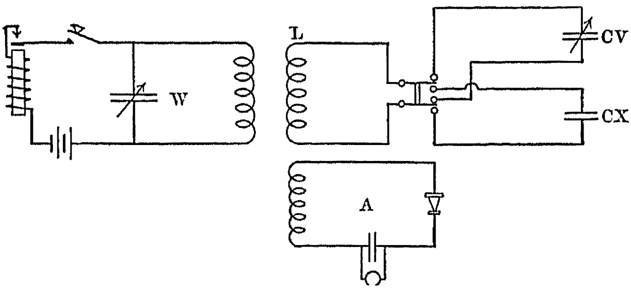


FIG. 37.—Measurement of capacity, substitution method.

odic receiving circuit is coupled very loosely to the closed oscillatory circuit, or better, as Prof. Pierce suggests, connect a detector and telephone unilaterally to the circuit to be measured, as in

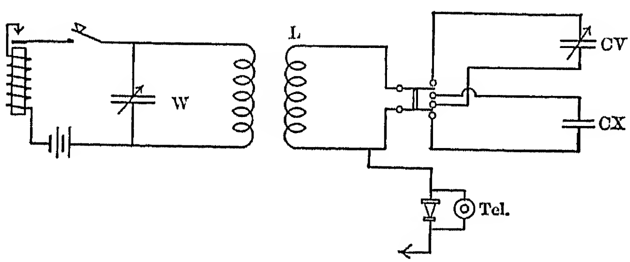


FIG. 38.

Fig. 38. The wave meter, *W*, is used as a sending set and tuned to the above-mentioned closed oscillatory circuit. Resonance is obtained when the sound in the receiver is loudest, and this will correspond to some distinct position of the variable condenser

of the wave meter. Then the variable condenser *Cv* is put in the circuit instead of *Cx*. *Cv* is varied until the two circuits are in tune, the wave meter circuit being kept as it was when used with *Cx*. The value of the capacity of *Cv* is then equal to the unknown capacity *Cx*, and if *Cv* is calibrated directly in centimeters or microfarads, or if a calibration curve is at hand show-

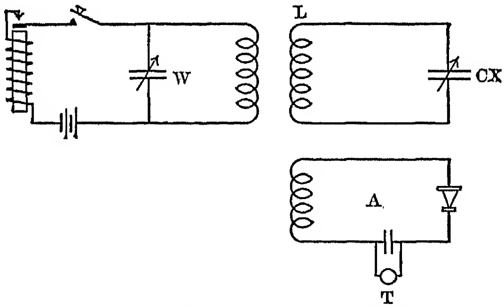


FIG. 39.—Measurement of capacity.

ing the values in microfarads or in centimeters for every setting in degrees of the condenser scale of *Cv*, the value of *Cx* is at once known.

**Capacity of a Condenser in an Oscillatory Circuit with a Known Inductance.**—A closed oscillatory circuit is made with a known inductance and the unknown condenser *Cx* (Fig. 39).

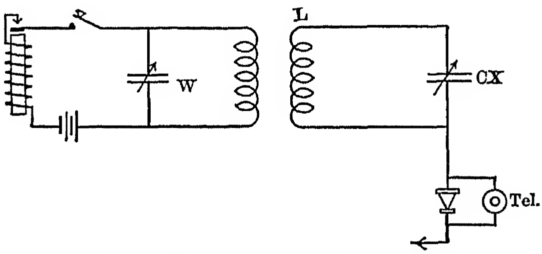


FIG. 40.—Measurement of capacity, Pierce.

The aperiodic circuit, *A*, is very loosely coupled with the closed oscillatory circuit, or a detector and telephone is unilaterally connected to the circuit to be measured as in Fig. 40 and the wave meter, *W*, is used as an oscillator and tuned to the closed oscillatory circuit *L*, *Cx*. Then the value of wave length obtained when the loudest sound is heard in the receivers, and the value

of the known inductance, are substituted in the following formula:

$$\lambda \text{ meters} = 59.6\sqrt{C \text{ mfds.} \times L \text{ cm.}}$$

and the equation solved for $C$.

Thus the wave length for resonance equals 534 m. and the known inductance is 20,000 cm. To find the unknown capacity.

$$C \text{ mfds.} = \frac{\left(\frac{\lambda \text{ meters}}{59.6}\right)^2}{L \text{ cm.}} = \frac{80}{20000}$$

$$Cx = 0.004 \text{ mfds.}$$

To avoid the labor of dividing and extracting the square root, etc., it is more convenient to refer to the logarithmic chart (see Fig. 42). Instructions for use will be found with the chart. This method of measuring capacity is correct only when the capacity of the wire of which inductance $L$ is constructed, is negligible. This is not the case when inductance $L$ is the primary or secondary of a receiving set, or the inductance coil of a wave meter, or an inductance of similar size.

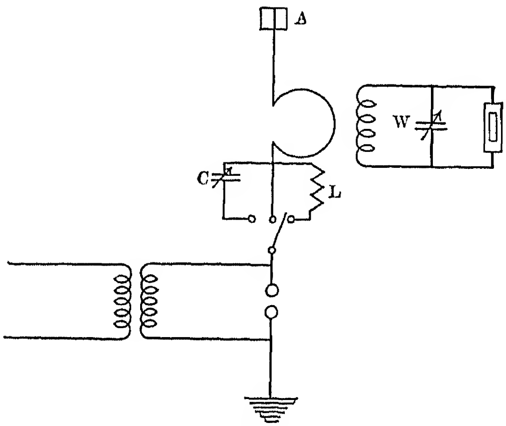


FIG. 41.—Measurement of the capacity of the Antenna.

**Measurement of the Capacity of the Antenna.**—The antenna circuit, Fig. 41, is excited by placing an open spark gap directly between antenna $A$ and ground, the spark gap being directly across the terminals of the secondary of the transformer, condenser and helix being cut out of circuit as when measuring the natural wave length of the antenna.

A large capacity, $C$, and a small inductance, $L$, are connected by means of a three-point switch, so that they can readily be cut into the antenna circuit as shown.

Let the natural wave length of the antenna itself be called $\lambda_a$. Suppose the wave length changes to $\lambda_c$ or $\lambda_l$ on the insertion of the capacity, $C$, or inductance, $L$, respectively. If the inserted capacity and inductance are so chosen that the wave lengths do not differ by a large amount, then the measurements of the three wave lengths will allow a closely approximate calculation of the capacity of the antenna, as follows:

$$C_c = \frac{C \times \lambda_a^2 - \lambda_c^2}{\lambda_c^2} \doteq 2C \times \frac{\lambda_a - \lambda_c}{\lambda_c}$$

$$C_l = \frac{\lambda_l^2 - \lambda_a^2}{4\pi^2 L} = \frac{(\lambda_l - \lambda_a)\lambda_l}{20L}$$

and,

$$C_a = \frac{C_c + C_l}{2}$$

Buzzer excitation may also be used.

**Determination of the Coefficient of Self-inductance.**—This supposes the possession of a condenser of known capacity.

A closed oscillatory circuit is constructed out of a known capacity, $C$, and an unknown inductance, $L$. An aperiodic receiving circuit is coupled with the above-mentioned closed oscillatory circuit, and the wave meter tuned to the latter circuit as in determining an unknown capacity (Fig. 39) or a unilaterally connected detector and telephone may be employed as shown in Fig. 40. The wave length at resonance is read from the wave meter. The known capacity being in mfds., the wave length in meters, and the unknown inductance in centimeters, we can find the value $L$ from the formula:

$$L = \frac{\left(\frac{\lambda}{59.6}\right)^2}{C \text{ mfds.}}$$

or, what is quicker and more convenient, find it by means of the logarithmic chart (see Fig. 42 and accompanying explanation). This method is correct only when the capacity of the unknown inductance itself is negligible, or is known and added to the value of the known capacity in the formula.

**Measurement of the Coefficient of Mutual Inductance.**—This measurement may, at times, be necessary for determining the mutual inductance between the primary and secondary of a receiving oscillation transformer or loosely coupled tuning coil.

A closed oscillatory circuit consisting of a condenser of known capacity and the unknown inductance to be measured, is connected as hereinafter described, acted upon by a wave meter which is tuned to the wave length of the circuit containing the unknown inductance, and the resonance point determined by the maximum sound in the receivers of an aperiodic circuit loosely coupled with the inductance under examination.

The two coils, in whatever relative position to each other it is desired to measure their mutual inductance, are first connected in series with each other and with the known capacity, so that the current flows in the same direction around both coils, and the inductance, $L_1$, is determined by wave metrical method. They are then joined in series with each other and with a known capacity, so that the current will flow in opposite directions around both coils, and the inductance $L_2$ then determined by examination with a wave meter. Then the formula connecting the mutual inductance, $M$, of these coils, with the two inductances just measured, is as follows:

$$M=\frac{L_1-L_2}{4}$$

Hence, given two coils, we can measure their mutual inductance in any position with respect to each other.

The mutual inductance of a transmitting oscillation transformer can also be measured by the above method.

**Determination of the Coefficient of Coupling.**—This is an important determination to be made at times in the case of the receiving transformer. It may be shown that the coefficient of coupling of two coils, $\tau$, is equal to the quotient of the mutual inductance of the two coils in any position, by the square root of the product of the separate inductances of the two coils, that is,

$$\tau=\frac{M}{\sqrt{L_pL_s}}$$

So, by the methods before given, we can measure the inductances $L_p$ and $L_s$, separately, by connection to a known capacity, and then measure the mutual inductance, $M$, as described above,

and, placing the values found in the formula, we get the true coefficient of the coupling between the two coils.

**Use of the Logarithmic Chart for Calculating the Frequency, Wave Length, Inductance and Capacity of Oscillatory Circuits.**—Where many calculations are required, instead of solving the formulæ before given, it is simpler, and, in general, sufficiently satisfactory to take the values desired from Fig. 42.

This chart gives directly the values of wave lengths from 300 to 3000 meters, with corresponding frequencies from 1,000,000 cycles to 100,000 cycles; for capacities from 0.0025 to 0.025 mfds: and for inductances from 10,000 to 100,000 cm. As will be shown later it can be applied to values of the variables other than those appearing on the chart.

To use the chart a straight edge is placed so as to cross the selected value of the known capacity on the capacity scale and the wave length read from the wave meter, on the scale of wave lengths; when the inductance is at once read from the intersection of the straight edge with the inductance scale.

*Case* 1.—Capacity and inductance known, to determine the wave length.

$$C = 0.005 \text{ mfds.} \qquad L = 55{,}800 \text{ cm.}$$

The straight edge placed on these values crosses the wave length scale at 1000 meters; hence, this is the required wave length.

*Case* 2.—Knowing the wave length to determine the corresponding frequency.

$\lambda = 600$. The corresponding frequency lying beside it on the adjoining scale is 500,000 cycles.

*Case* 3.—Knowing the wave length and capacity, to find the corresponding inductance.

$$\lambda = 900 \qquad C = 0.019 \text{ mfds.}$$

The straight edge placed to cross the wave length scale at 900 meters and the capacity scale at 0.019 cuts the inductance scale at 12,000 cm., the required inductance.

**Corrections for Values of Inductance or Capacity Greater or Less than the Values Given on the Chart.**—From the formula $\lambda = 59.6 \sqrt{L \text{ cm.} \times C \text{ mfds.}}$ it is seen that the wave length varies directly as the square root of both the inductance and the

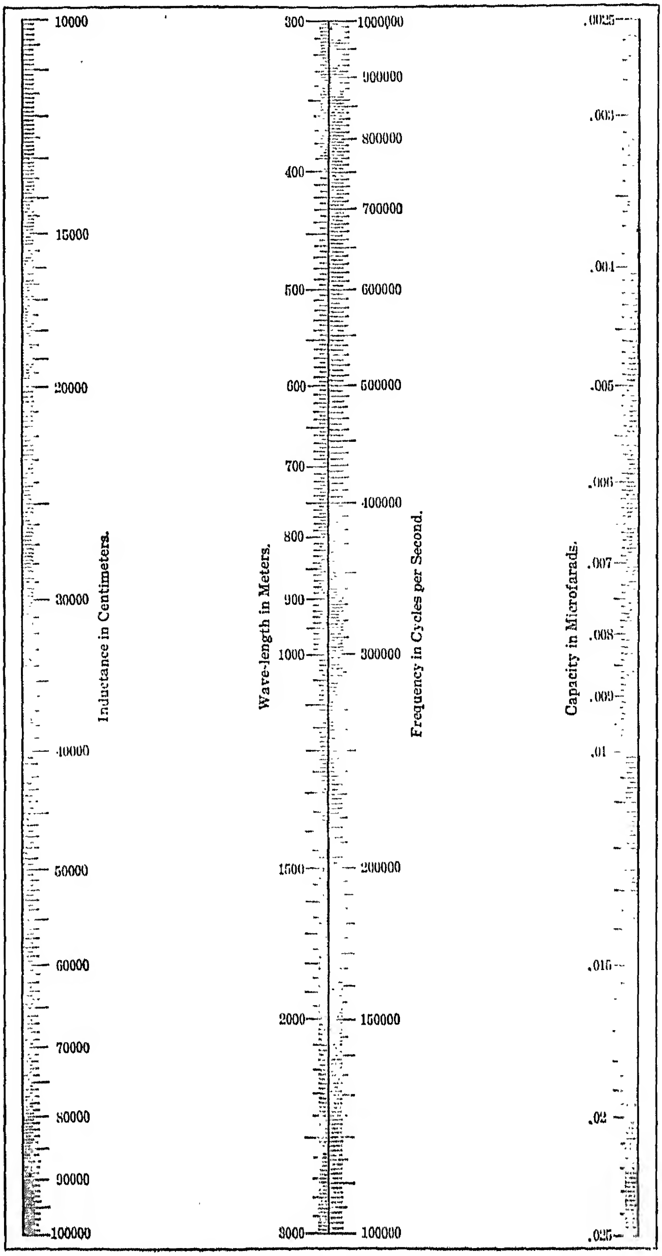


FIG. 42.—Logarithmic chart.

capacity: so, if either the inductance or the capacity be multiplied by any number, the wave length is to be multiplied by the square root of that number.

A capacity 100 times as large as the value shown on the chart would, with the given inductance, produce a wave length 10 times the value shown by the intersection of the straight edge with the scale of wave lengths, and a corresponding frequency of one-tenth of the value indicated by the frequency scale.

*Case* 4.—$C=1$ mfd. and $L=63{,}500$ cm. What will be the resulting wave length and frequency?

$$1 \text{ mfd.} = 0.01 \text{ mfd.} \times 100$$

Setting the straight edge to intersect the capacity scale at 0.01 mfds., and the inductance scale at 63,500 cm., the straight edge intersects the wave length scale at 1500 meters. Multiplying this by 10 gives 15,000 meters, the required wave length. One-tenth of the frequency, 200,000, corresponding to the 1500 meter wave length, will be the frequency for 15,000 meters.

In case the chosen capacity or inductance is ten times, or one-tenth as large as any value on the chart, the wave length read from the chart will have to be multiplied or divided by the square root of 10, or 3.162. This multiplication or division may be performed graphically as follows:

From the point on the chart where the straight edge crosses the wave length scale, lay off on this scale a distance equal to one-half the length of the scale. This distance is laid off to whichever side makes it fall completely on the scale. The point thus found will be the desired wave length. Laying off the half scale length to the right divides the wave length value by the square root of 10, and laying it off to the left multiplies by that value. As the result obtained by multiplying by the square root of 10 is 10 times as great as the result obtained by dividing by the square root of 10, it will be necessary, in order to get a correct result, where we have been obliged to lay the distance off to the left, instead of to the right as desired, to divide the result obtained from the chart by 10.

*Case* 5.—$C=0.001$ mfd. and $L=20{,}000$ cm. What wave length will result?

Intersection at 842 meters. To get correct result we must divide the result by the square root of $10=3.162$. Lay off one-half length of wave length scale from 842 to left, since it cannot

be placed to the right. This gives the wave length as 2660 meters which is 10 times too large, since to divide we should have laid off the distance to the right, hence, $2660 \div 10 = 266$ meters, the correct wave length.

*Case* 6.—Measurement of inductance. $C = 0.001$ mfd. $\lambda =$ 3000 meters. What is the value of inductance?

Lay off from 3000 meters to the right on the middle scale a distance equal to one-half the scale of wave lengths. This point is approximately 950 meters. A straight edge placed on this point and the capacity 0.01 (a reading on the scale 10 times larger than the value of the known capacity), will intersect the inductance scale at 25,200 cm. This reading must be multiplied by 10 to give the correct reading, 252,000 cm.

*Case* 7.—Measurement of capacity.

Known inductance $= 15,000$ cm. $\lambda = 300$ meters. Capacity?

From 300 lay off a distance equal to one-half the length of wave length scale. This locates a point 950 meters, on which place straight edge which has been pivoted on point on inductance scale marked 15,000 cm. The straight edge intersects the capacity scale at 0.017 mfds. To obtain the correct reading it is evident that it is necessary to take one-tenth of this reading, since 10 times the capacity was used. The true reading is, therefore, 0.0017 mfds.

*Case* 8.—Where values of neither inductance, capacity or wave length are found on the chart.

The capacity of an antenna is 0.001 mfds. What must be the value of the inductance in circuit, that the wave length may be 5000 meters?

500 meters is one-tenth of the value of the true wave length.

0.01 mfds. is 10 times the value of the real capacity.

Lay off one-half of wave length scale from 500 meters. This gives a point, 1572 meters, through which a straight line from 0.01 on the capacity scale gives 70,225 cm. as the intersection on the inductance scale. Since 10 times the real value of the condenser, and only one-tenth of the value of the wave length were used, the inductance will be $10 \times 10$, or 100 times as great as the value read from the scale, or, 7,022,500 cm. or 7.0225 millihenrys.

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